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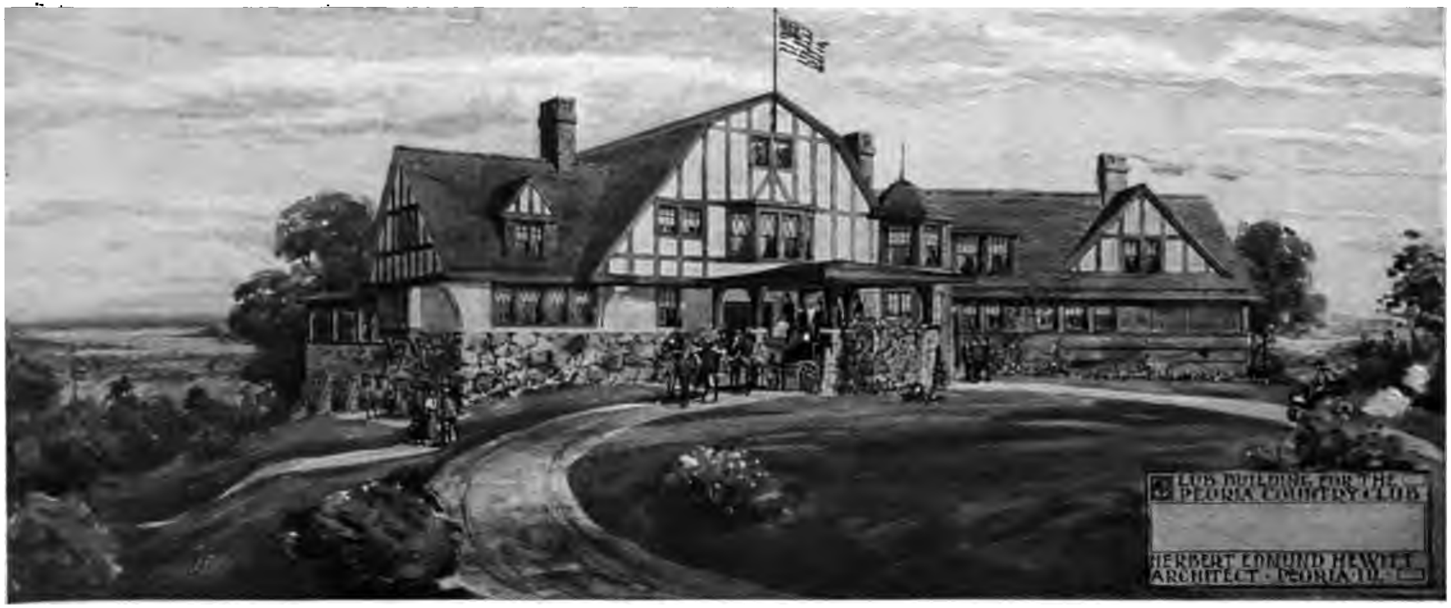

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Herbert Edmund Hewitt, Architect, Peoria, Ill. For plan, see next succeeding plate.

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Grateful acknowledgment is here made also for the invaluable co-operation of the foremost architects, engineers, and builders in making these volumes thoroughly representative of the very best and latest practice in the design and construction of buildings; also for the valuable drawings and data, suggestions, criticisms, and other courtesies.

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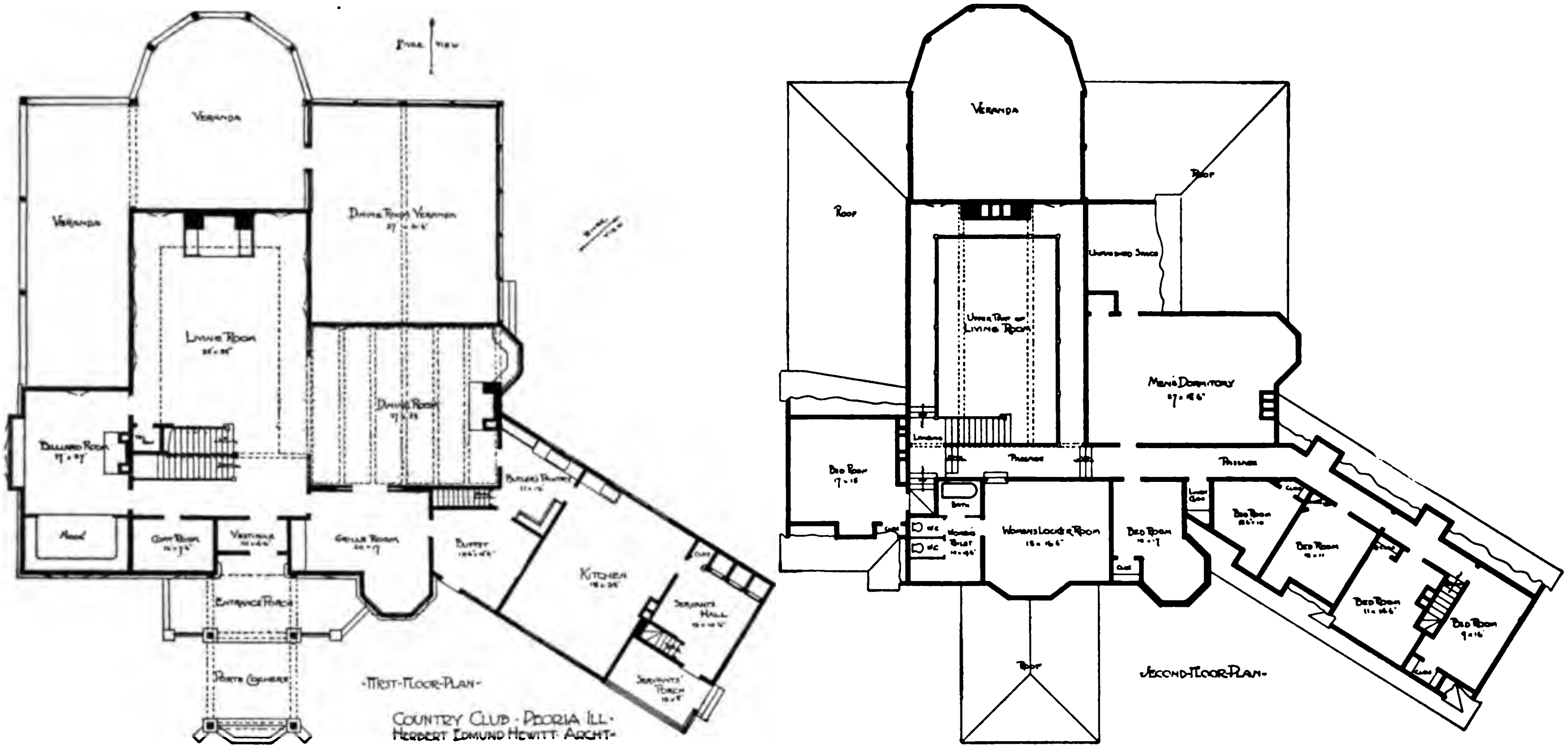

PLANS OF THE PEORIA COUNTRY CLUB, PEORIA, ILL.

Herbert Edmund Hewitt, Architect, Peoria, Ill.

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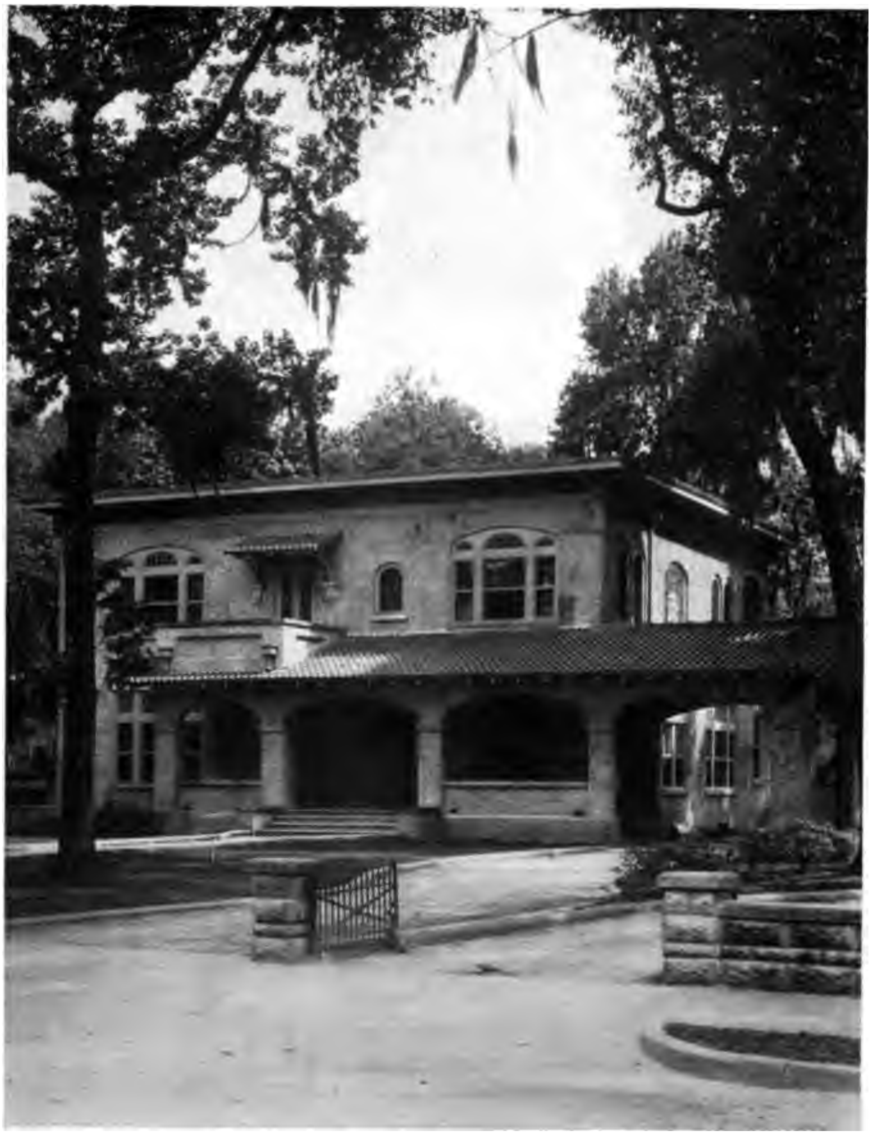

CONCRETE RESIDENCE AT OCALA, FLORIDA

Foreword

THE rapid evolution of constructive methods in recent years, as illustrated in the use of steel and concrete, and the increased size and complexity of buildings, has created the necessity for an authority which shall embody accumulated experience and approved practice along a variety of correlated lines. The Cyclopedia of Architecture, Carpentry, and Building is designed to fill this acknowledged need.

¶ There is no industry that compares with Building in the close interdependence of its subsidiary trades. The Architect, for example, who knows nothing of Steel or Concrete construction is today as much out of place on important work as the Contractor who cannot make intelligent estimates, or who understands nothing of his legal rights and responsibilities. A carpenter must now know something of Masonry, Electric Wiring, and, in fact, all other trades employed in the erection of a building; and the same is true of all the craftsmen whose handiwork will enter into the completed structure.

¶ Neither pains nor expense have been spared to make the present work the most comprehensive and authoritative on the subject of Building and its allied industries. The aim has been, not merely to create a work which will appeal to the trained expert, but one that will commend itself also to the beginner and the self-taught, practical man by giving him a working knowledge of the principles and methods, not only of his own particular trade, but of all other branches of the Building Industry as well. The various sections have been prepared especially for home study, each written by an acknowledged authority on the subject. The arrangement of matter is such as to carry the student forward by easy stages. Series of review questions are inserted in each volume, enabling the reader to test his knowledge and make it a permanent possession. The illustrations have been selected with unusual care to elucidate the text.

¶ The work will be found to cover many important topics on which little information has heretofore been available. This is especially apparent in such sections as those on Steel Construction; Reinforced Concrete Construction; Building Superintendence; Estimating; Contracts and Specifications, including the principles and methods of awarding and executing Government contracts; and Building Law.

¶ In conclusion, grateful acknowledgment is due the staff of authors and collaborators, without whose hearty co-operation this work would have been impossible.

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UNDERWRITERS' LABORATORIES, CHICAGO

UNDERWRITERS' REQUIREMENTS

PART I

INTRODUCTION

The insurance interests are concerned with electric work only for the reason that such work if done improperly constitutes a fire hazard, and underwriters' rules on electrical installations are, therefore, confined to such questions as concern proper methods and materials to be employed to minimize the chance of fire arising from the use of electricity for light, heat, and power. Electricity as employed for signaling work, such as telegraphs, telephones, call bells, burglar alarms, and similar purposes, is not covered by insurance rules except in so far as such installations may become dangerous because of the liability of wires in such systems becoming crossed with electric light, heat, or power circuits.

The many applications of electricity for municipal fire-alarm systems, factory or isolated plant fire alarms, watchman's time-recording appliances, and automatic alarms employing electric thermostats, are not covered by the general rules for electric work. They do not in general tend to cause a fire hazard of themselves but come rather under the head of protective devices and the discussion of them does not, therefore, come within the scope of this paper.

The earlier installations of electrical lighting and power appliances were very crude and were often made with no consideration of what are now generally admitted to be questions of great importance from the viewpoint of fire protection. It was natural that experience should have been necessary to demonstrate the need of protection against unreliable or hazardous methods of applying electricity and to develop improved materials and devices. The comparatively mysterious nature of electricity as viewed by the general public led at first to a habit, not yet wholly outgrown, of attributing to electrical causes all fires for which no other cause was readily apparent. Today, however, the production of light and the transmission of power are without question accomplished more safely as well as more conveniently and economically by electricity than by any other means.

In judging electrical work as affecting the fire hazard, the fire-protection engineer and underwriters cannot undertake to do for the assured, the work which lies within the province of the electrical engineer on whom properly falls the responsibility of designing installations and choosing the methods and materials to be used to accomplish the results desired. In electrical, as in other engineering, considerations of first cost, economy of operation and maintenance, efficiency of machinery and appliances, depreciation, and reliability are of prime importance. It is the proper function of the fire-protection engineer to act as critic of the plans and their execution in order that other considerations involved shall not be allowed to dictate methods which do not afford suitable and reasonably safe fire conditions. Electrical engineering is far too complicated a profession to be fully mastered by the fire-protection engineer or by an inspector, but the general principles of safe electrical work can be mastered and applied without presuming to encroach on the work of either the consulting or the installing engineers.

Architects are now very generally prepared to recognize the necessity of providing in their plans for the electrical installations which in more elaborate buildings must be given very careful attention if adequate provision is to be made for electric wires and appliances. It is in the smaller and less carefully planned structures that the electric work is most likely to be left to the installers to be put in as best it may. A well considered plan adapted to the type of building and the uses to be made of current is an essential to successful and safe work. Makeshifts are usually dangerous. For this reason, also, it is often much more difficult to secure proper electrical work in wiring old buildings than new ones.

Electrical contractors are usually willing to do good work for a fair price and most poor work is due to an attempt to secure business at too low rates in order to meet competition. Since a faulty or dangerous electrical installation may perform its appointed work, and since electrical defects are not easily discovered, often developing after some time, only thoroughly good work from the start affords real protection against disastrous failure from causes which, after a fire, may be very difficult to assign but which might have been easily foreseen and removed.

Electrical inspectors either of the underwriters or of the municipality should be fully acquainted with approved methods, rules, reasons for rules, and must have a great range of practical knowledge which only actual field experience can give; and such inspectors must be specialists of a high order. The fire-protection engineer must refer to such specialists the technical details while undertaking himself to be a competent judge of general methods and principles.

Electricity as a Cause of Fires. Electricity may in general be the cause of a fire in either one or both of the following ways:

First: By causing wires, cables or other conductors to be overheated by the passage of the "electric current," thereby setting fire to the insulations on such conductors or to nearby combustible materials. All conductors are heated by any current however small, but if the conductor is badly overloaded it may become red- or even white-hot. Hence it becomes necessary to prescribe the safe carrying-capacity of wires, and all conducting parts of electric appliances must be properly proportioned. Such parts as are peculiarly liable to become heated or which must be heated to perform their proper function must be suitably protected and separated under all circumstances from materials which might be ignited.

Fuses, circuit breakers, and other automatic appliances have to be installed to afford protection in case of accidents which may result in conductors or other devices being overheated by abnormally large currents. Such protective devices may themselves become dangerous and the rules, therefore, prescribe carefully how they must be constructed and installed. Overheating of conductors is thus one of the two general ways in which electricity may cause a fire and provisions against such accidents, therefore, form an important part of the rules.

Second: Electricity may form "arcs." An arc is the visible evidence that the current is passing from one conductor to another or across a break or gap through the air or over the surface of an insulating material. An arc always causes heat and if any appreciable current passes, the arc will be very hot and if continued is capable of melting the adjacent metal at the gap or setting fire to any combustible matter near by. It, therefore, becomes necessary to prescribe rules, the observance of which tends to lessen the chance of accidental arcs being established, and to so locate all appliances, the operation of which produces arcs, that no harm will result. Switches, circuit breakers, and fuses are all "arcing" devices. The problem of insulation, spacing between conductors and excellence in materials, methods of installation and workmanship, all have to do chiefly with the prevention of accidental or dangerous arcs.

From the viewpoint of fire hazard, it is well to treat all conductors, however well insulated, as bare, and to proceed to furnish adequate protection against grounds or short-circuits on that basis.

In judging of installations it must constantly be kept in mind that conditions are liable to become worse rather than better after the wiring and appliances have been in use for some time. Requirements are, therefore, made to anticipate in part such deterioration as is inevitable in even the best equipments, and which may be surprisingly rapid when inferior materials are put in by careless workmen and used and abused by those having little or no understanding of electrical affairs and no appreciation of the hazards involved.

The following are the chief general requisites for a safe electrical installation: Excellence of material; simplicity in design so far as compatible with the results to be secured; ease of inspection and repairs of all wiring and appliances; thoroughly good mechanical execution of the work; the choice wherever possible of the more protected and safer forms of wiring; and the use of "approved fittings." No rules can take the place of good designing nor will perfunctory obedience of rules make a poorly executed job, safe. The architect, the owner, the manufacturer of devices and materials, the electrical contractor, the electricians who install and those who operate the plant—each and all must share the responsibility with the insurance and the municipal inspector.

Elementary Electrical Ideas and Terms. Electric power may be transmitted by either direct or alternating current.

Direct Current. Direct current is current of such character that what is usually called the "direction" of the current is always the same, or, more exactly, the magnetic effects of the current are not being reversed from instant to instant. If a small compass be held near a wire carrying direct current, the needle may be caused to turn away from its natural north and south line. Thus in Fig. 1, if *D* is a direct-current generator connected to a wire from south to north, a compass needle over the wire, before the switch *T* is closed, will point along the wire; when the switch is closed, if current flows as shown by the small arrows on the wire, the needle will turn as shown. The amount it will turn is an indication of the amount of current, but the needle will remain stationary in its new position if the current is direct current. A battery gives direct current and so does a direct-current generator.

Alternating Current. If, however, the current came from an alternating-current generator or from a transformer supplied by such a generator, the needle would tend to swing very rapidly first to one side of the wire, and then to the other. This would also be the case if the connections on the direct-current machine, Fig. 1, were rapidly exchanged back and forth. Such reversals of current direction are made automatically by an alternating-current generator. The number of changes per second is called the frequency and 25, 60, and 135 are the commonest commercial frequencies of alternators. Evidently no compass needle could actually vibrate so fast, but it *tends* to do so, and the result is that the needle does not appear to be affected by the alternating current.

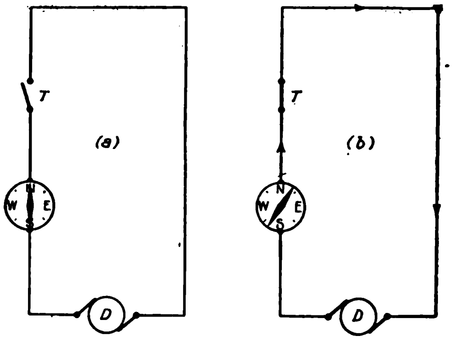


Fig. 1. Diagram of Simple Generator Circuit Showing Effect on Magnetic Needles

Both direct- and alternating-current systems are in common use for light and power. Street railways use at present chiefly direct-current systems. Where power must be conveyed to considerable distances, alternating current is used because it is more economical under these conditions. Different motors and somewhat different arc lamps are required for direct and for alternating circuits. Incandescent lamps are the same for either system as are also most heating devices. Transformers can be used only on alternating-current systems.

The distinction between direct and alternating current is not one which has many important consequences in the safeguarding of electrical work. There are, however, a few important cases where different rules are established. It should be remembered that direct and alternating currents of the same strength produce the same heating effect in a given conductor. In some cases, however, with alternating currents an additional heat effect is produced in certain appliances by the magnetic action of iron cores, of coils, or other parts of the apparatus. In general, alternating current produces less severe and persistent arcs than direct current of the same strength and voltage. Furthermore, alternating-current motors in particular are somewhat less liable to emit sparks and, therefore, have a certain advantage. As a whole, however, no distinction may be made as regards fire hazard between direct- and alternating-current installations which should be made with the same care in workmanship and with the same precautions as to insulations, fuses, and all protective devices.

Current. Current is measured in *amperes.* It may be compared to the number of "gallons per minute" carried by a water pipe through which a stream is flowing. More "current" will, other conditions being equal, do more work, and will always cause more heat in the conducting wires and cables and in the appliances, lamps, heaters, resistances, motors and the like which use the current. Furthermore, the heating effect in conductors such as metals varies with "the square of the current," *i. e.,* if one unit of current produces a certain amount of heat in a wire, *twice* as much current will cause *four* times as much heat in the same wire, *three* times the current will cause *nine* times the heat and so on. An instrument for measuring current is called an ammeter.

NOTE. The heat liberated is a measure of energy or power consumed in the wire. The *temperature* of the wire will not necessarily follow the rule given above, this being dependent not only upon the heat developed but also upon the surroundings of the wire as affecting the readiness with which the heat may be radiated or otherwise gotten rid of.

Voltage. Voltage or potential is measured in volts. *Volts* measure the propulsive force which causes "current" to flow through a conductor. It may be thought of as an electric pressure produced by the dynamo, battery, or other generator of electricity. Through a given circuit a higher voltage will in general cause a proportionally greater current. Since it is the voltage which may cause electricity to pass from its proper path and seek other and perhaps dangerous paths, higher voltages require better insulation on wires and in all electrical appliances. The voltage used thus becomes an important factor in determining the protection necessary for safety.

Difference of Potential. Two points, as on conductors or between a conductor and the earth, are said to be at *different potentials*. When such an electrical condition exists on them a current *tends* to pass between them either along the conductor or across a gap between the points. Along the conductor such a current produces heat, while if the current "jumps the gap" or *arcs*, heat is produced in the spark or arc formed.

Resistance. Resistance is measured in *ohms*. All substances offer resistance to the passage of current. This is true of metals, liquids, and gases. A good conductor, such as copper, has comparatively little resistance. Other materials, such as slate, porcelain, and rubber, are very poor conductors and may generally be considered as *insulators*. Since heat is always produced, the conductors must be of suitable size and material to keep the temperatures below the dangerous values, or, in cases where the heat is the result desired, suitable protection must be provided. The resistance of conductors is thus a necessary but undesirable property in some ways and a usable and valuable property in others. In all cases the fact that current produces heat in conductors must be reckoned with in electrical problems.

The loss of power from the heat expended in a supply wire is an illustration of the undesired property of resistance. The electric flatiron is an appliance where the resistance produces a useful result.

Ohm's Law. For our purpose here the relation between current, voltage, and resistance in a direct-current circuit may be stated as follows: The current (amperes) in a circuit equals the voltage (volts) divided by the resistance (ohms), or $I=\frac{E}{R}\cdot$ This is true both of entire circuits and parts of circuits, provided E and R are the voltage and resistance of the whole circuit or the part under consideration, respectively. For a. c. circuits a somewhat more elaborate formula must be used.

Power. Power is measured in *watts.* (A kilowatt is 1,000 watts.) In direct-current circuits the power expended in any portion of the circuit is obtained by multiplying the current in amperes by the voltage across the portion of the circuit. Thus: If the current in an incandescent lamp is ½ ampere and if a voltmeter shows that the voltage across the lamp terminals is 110 volts, the power is 55 watts.

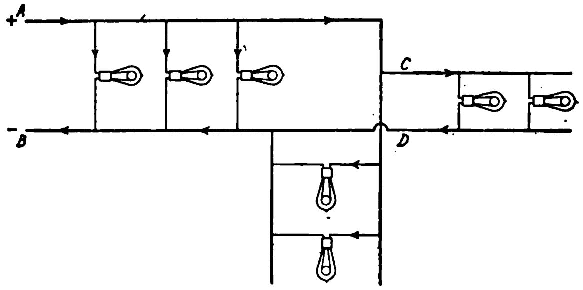


Fig. 2. Multiple Lamp Circuits

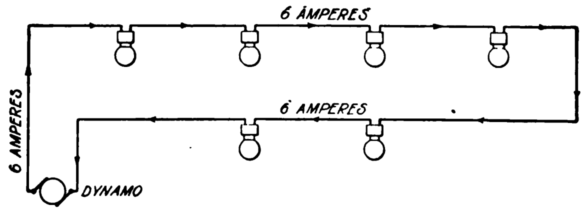


Fig. 3. Series Arc-Lamp Circuits

The corresponding mechanical term is horse-power; 1 horse-power is equivalent to 746 watts and 1 kilowatt equals about 1⅓ horse-power. With alternating current the power in watts is not always to be obtained by multiplying amperes by volts. With alternating currents, a third factor must be used, called the "power factor" of

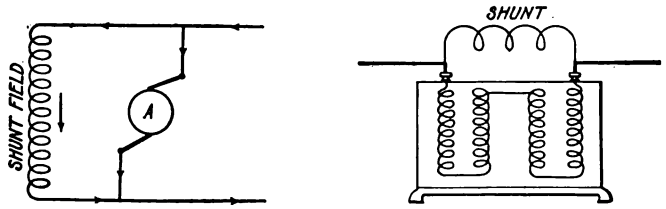


Fig. 4. Diagram of Shunt Circuits

the circuit. It is sufficient for our purpose here to remember that the power actually delivered and used with alternating current *may be less* than the simple product of amperes and volts. Thus, if a current of 50 amperes as read by an ammeter, passes through a coil of wire, and the voltage across the terminals of the coil is 100 volts, the power consumed, if the current is direct, is 50×100=5,000 watts or 5 kilowatts. If, however, the coil surrounds an iron core (as in an electromagnet) and alternating current is used, the power consumed will not be 5 kilowatts. The power factor may be 60 per cent for this coil, and the power consumed will then be 50×100×.60=3,000 watts or 3 kilowatts, instead of 5 kilowatts. The following definitions will be useful to those unfamiliar with electrical terms.

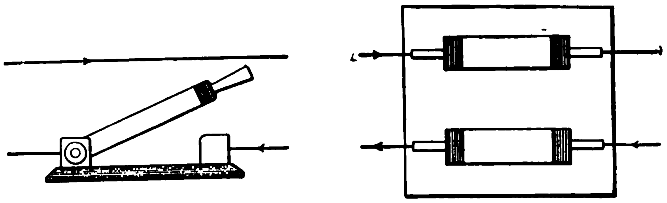


Fig. 5. Single-Pole Switch and Double-Pole Fuses

Multiple Connection. When a number of devices such as lamps, motors, etc., are so connected that the current has a path through each device separately from one supply wire to another, they are said to be connected in *multiple*. See Fig. 2. Incandescent lamps are almost always connected in multiple. In Fig. 2 if each of the 7 lamps shown takes 1 ampere of current the total current at *A*

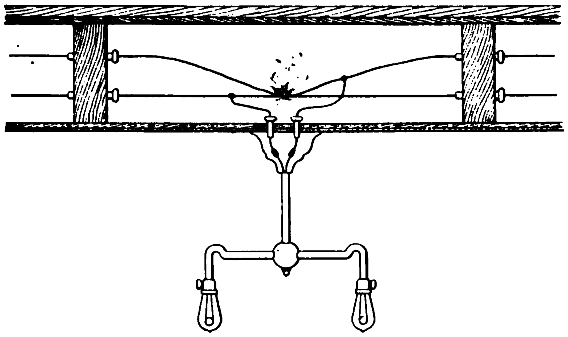


Fig. 6. Short Circuit in the Floor Above Chandelier

and at *B* will be 7 amperes, while at *C* and at *D* it will be 2 amperes.

Series Connection. When a number of devices are so connected that they come one after another, they are said to be connected "in series." In Fig. 3, the arc lamps are shown so connected. In this case the same current traverses all parts of the circuit and the total current is no more and no less than the current in each connected series device.

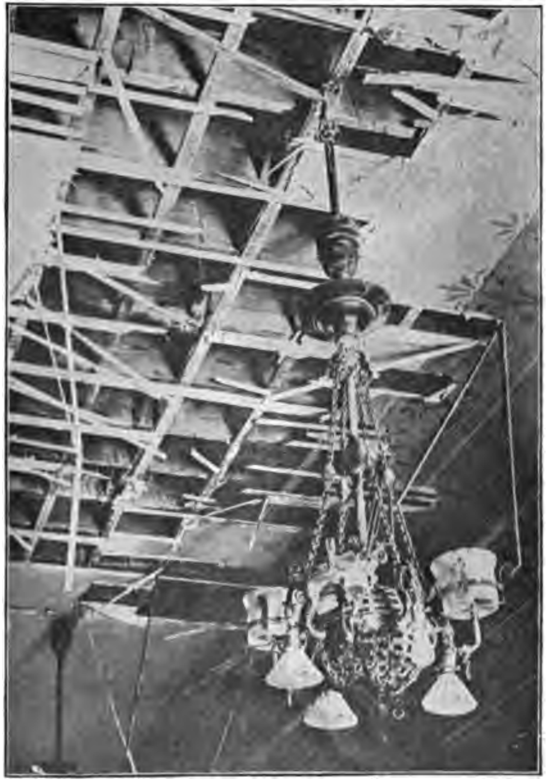


Fig. 7. Effects of a Short-Circuit in Wires Under Floor

Shunt. A shunt is a by-path between two points so connected that part of the current will traverse it. The division of the total current between the main path and the shunt will depend on the comparative resistances, the larger current going by the path of lower resistance. In Fig. 4 are shown the connections of a "shunt motor" and resistance box "shunted" by a wire.

Cut-Out. A cut-out is a device for automatically breaking a circuit, usually when the current reaches a predetermined value. Thus, a 60-ampere fuse is a cut-out designed to burn out when currents in excess of 60 amperes pass through it. A circuit breaker is an electro-mechanical switch which is also used as a cut-out.

Switches, fuses and other appliances are said to be *single-pole* if they are for but one wire of a circuit; *double-pole* if for two, *triple-pole* if for three. Fig. 5 shows a single-pole switch and a double-pole fuse.

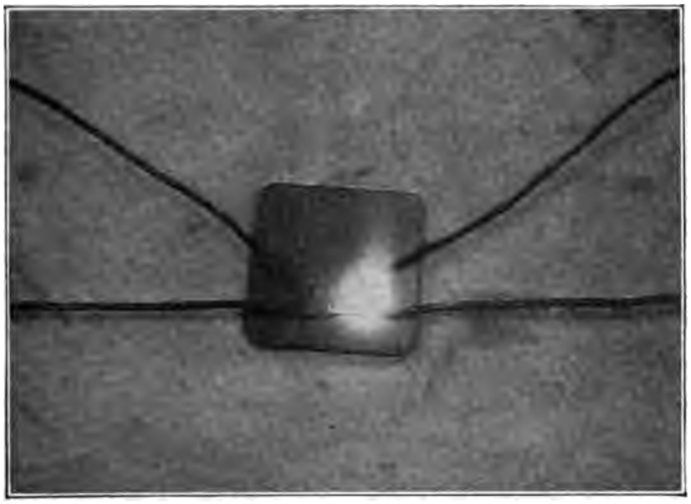


Fig. 8. Arc Between Wires of 250-Volt Circuit

Ground. A ground is a connection either intentional or accidental between a part of an electric circuit and the earth, or any metal or other conducting substances which are in electrical connection with the earth, such as water and gas pipes, iron beams, etc.

Short-Circuit. A short-circuit is a connection which permits current to flow from one part of a circuit to another by any path which it is not intended it should take. Since such a connection is the result of accident or the failure of some insulation, and since it usually allows excessive currents to flow, a short-circuit may be very dangerous and liable to cause a fire, especially as the accidental connection may afford very poor contact and cause arcing and burning at the junction of the conductors. Fig. 6 illustrates a short-circuit in a floor between the two supply wires to a chandelier installed on the ceiling below. The effect of this short-circuit is shown in Fig. 7. Fig. 8 is from a photograph of an arc produced by a 250-volt, 10 ampere current between two wires which were touched together at a point where the insulation had been destroyed.

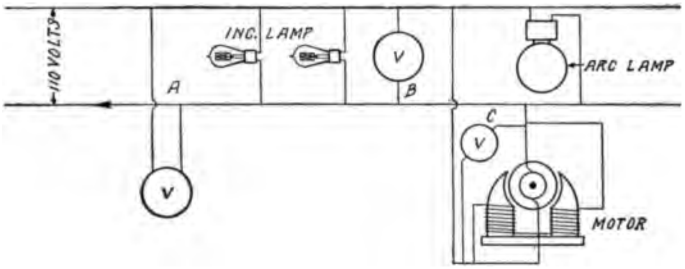


Fig. 9. Diagram of a Constant-Potential System

Constant-Potential System. A constant-potential system is one in which the voltage between the main supply wires is approximately the same at all points. Such a system is supplied by a constant-potential generator, which is of a character to furnish greater current as more devices, lamps, motors, etc., are put into use. Most in-

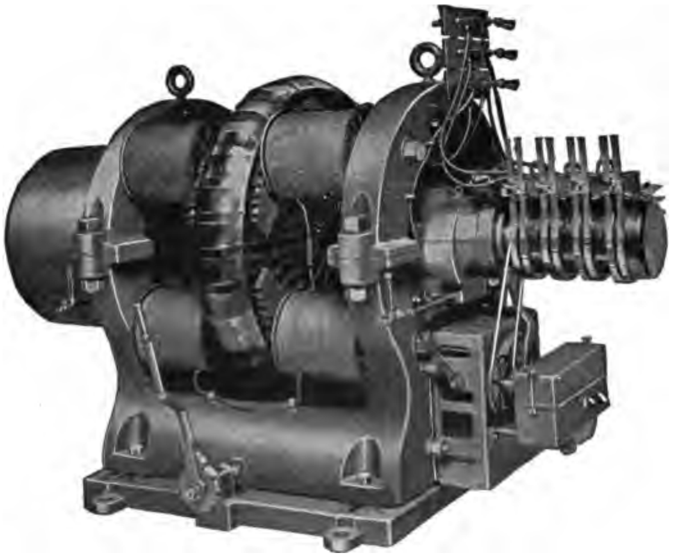


Fig. 10. Series Arc-Lamp Generator

candescent-lamp, motor- and street-railway circuits are of this type and also many arc-lamp circuits. Fig. 9 shows such a 110-volt system and if the distributing wires are properly chosen the voltmeters at the points *A*, *B* and *C* will all read approximately 110 volts. Devices on such currents are connected in multiple.

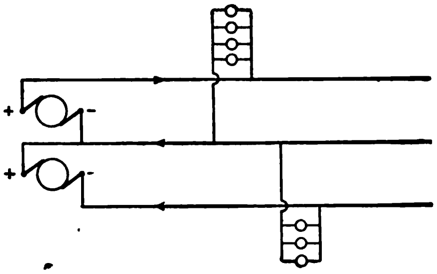


Fig. 11. Diagram of a Three-Wire Circuit

Constant-Current System. A constant-current system is one in which the current is automatically maintained approximately the same regardless of the number and character of the power-consuming devices in use on the circuit. Devices, usually arc lamps, are connected in series and the generator is of a type which automatically increases the voltage or electric pressure as more lamps are turned on. Fig. 3 shows such a circuit and Fig. 10 is a picture of a generator used for series arc-lamp work.

Two-Wire System. A two-wire system is one having a single pair of distributing wires.

Three-Wire System. A three-wire system is a special form of a multiple system usually employing two generators. Fig. 11 shows such a system with two-wire branches to incandescent lamps.

Transformers. The chief advantage of alternating over direct current lies in the fact that electric power can by alternating current be transmitted at a *high voltage* from the generating station to the point where the power is to be used, and there *transformed* with small loss to a voltage better suited to motors and lamps.

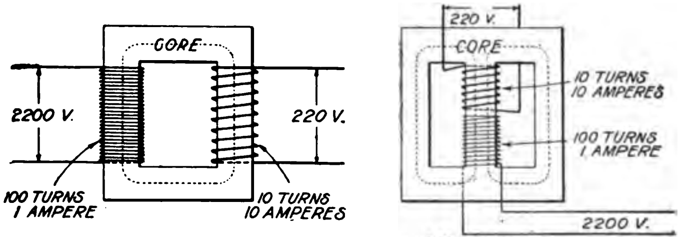


Fig. 12. Diagram of Two Types of Transformer

It is far more economical to transmit power at high voltages. It can be shown by electrical theory that by using twice as high voltage, a wire only one-fourth as large is needed to transmit a given amount of power with the same percentage of loss on the transmission line. It should be remembered that if the voltage is doubled the current need be only half as great in order to have the power delivered the same. But half as much current heats the wire which carries it only one-quarter as much and, since the heat dissipated on the wire is lost power, it is evident that economy requires that transmission of electric power be accomplished by high voltage and relatively small currents rather than the reverse. Thus it may be commercially possible to utilize a water power at a distance from a city to make high-voltage current which can economically be transmitted to the city over a line of rather small copper wires. It would never do, however, to carry this high-voltage current into buildings on account of the great fire risk involved, for the insulations in wiring cannot be made safe for high voltages. With direct current there is no very economical way to change a small current at high voltage into a larger current at a lower and safer voltage. With alternating current, however, this can be done very readily by means of a "transformer," a device which consists in its simplest form of two entirely separate coils of wire wound on the same iron core; in fact, a sort of double-coil magnet.

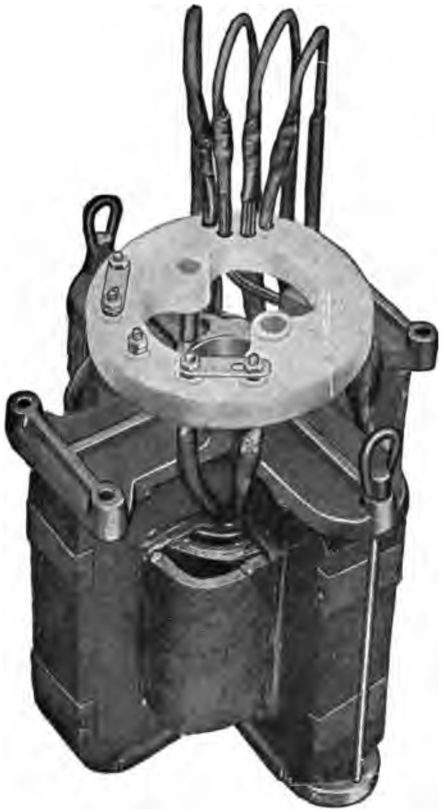


Fig. 13. Interior View of Incandescent-Lighting Transformer

Fig. 12 shows two shapes which a transformer may take. In each diagram suppose an alternating current at 2,200 volts and 1 ampere is supplied to one coil of 100 turns. Then a current of 220 volts and 10 amperes will be induced in the other coil which has but 10 turns, that is, the voltage will be "stepped down" in the same ratio as the number of turns on the *primary* (power-supply) coil and *secondary* (power-using) coil, and if there were no power loss in the transformer itself, the current would be multiplied by the same ratio inverted. In the case illustrated there are one-tenth as many turns in the secondary coil as in the primary and, therefore, the secondary voltage will be $\frac{2200 \times 1}{10} = 220$ volts, and the secondary current will be approximately ten amperes for every ampere supplied to the primary. If the power were supplied to the coil of the transformer having few turns, and used by the current induced in the coil having more turns, we should have a "step-up" instead of "step-down" transformer.

It should be especially noted that the action of a transformer depends wholly on the principle that the rapid changes and reversals of current in one coil will induce currents in the other coil. Alternating currents are rapidly and systematically changing and reversing currents, and thus transformers can be used to change the voltage and currents in a. c. circuits. Direct currents do not change in amount and direction and, therefore, transformers cannot be used at all on direct current.

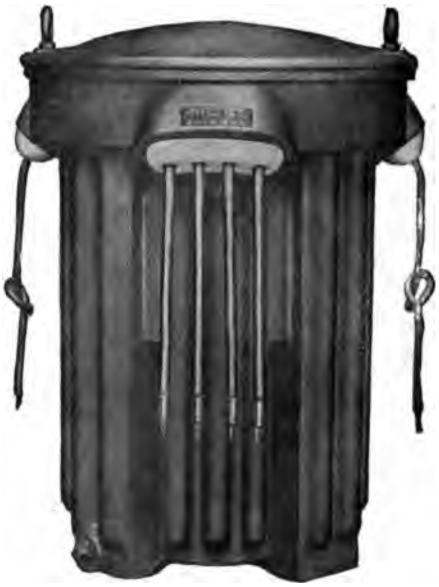


Fig. 14. Exterior View of Incandescent Lighting Transformer

Figs. 13 and 14 show the interior and exterior views of a small transformer of a type used for incandescent lighting. The case is designed to be filled with oil. Transformers are constructed of all sizes up to very large units, and are cooled either by air, air blast, oil, or by forced circulation of oil through the windings and core.

Alternating-current dynamos and transformers are constructed and connected in several ways which differ in regard to the number of partially independent circuits which they supply. An a. c. circuit in which there are but two wires from the generator to the transformer or to lamps or motors is called a *single-phase* circuit. Fig. 15 shows the path of the current in a single-phase circuit which includes a generator *G*, switches and with ammeter *A* and voltmeter *V*, transformers *TT* supplying power to lamps *L* and single-phase motor *M*. Single-phase circuits are used for lighting, both incandescent and arc, and for power.

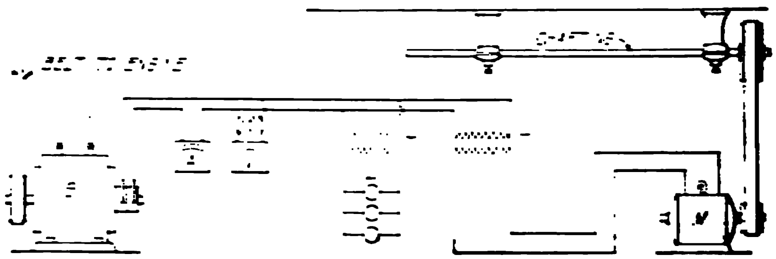


Fig. 15. Diagram of Single-Phase Light and Power Circuit

The other most common type of a. c. circuit is called *three-phase*, and is also used both for light and power. The essential parts of such a system are shown in Fig. 16 where it will be noted that the dynamo has three slip rings, the circuit has three wires and the transformer has three coils in the primary T_1, and three in the secondary T_2. In a three-phase circuit each pair of wires carries what may be considered a separate alternating current which varies in each pair in regular cycles, so that the maximum current in each phase or pair of wires is reached at different instants of time. Such circuits are very widely used, especially for power, with what are known as three-phase induction motors.

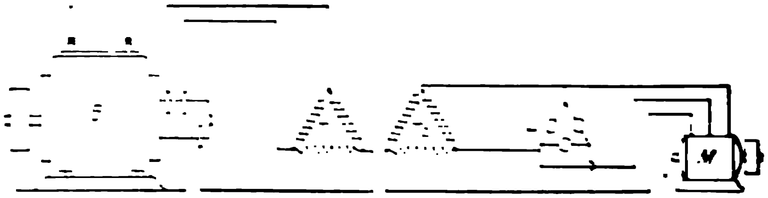
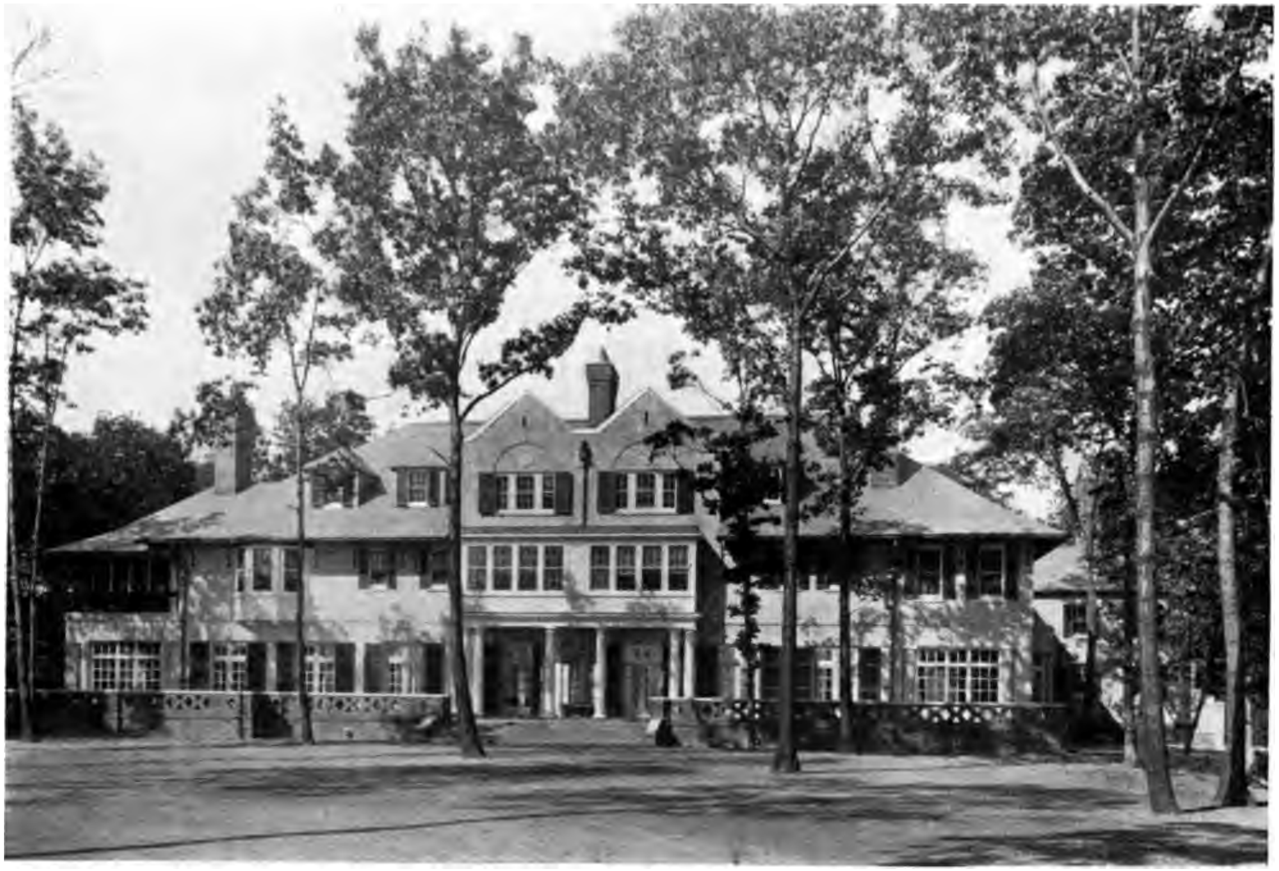
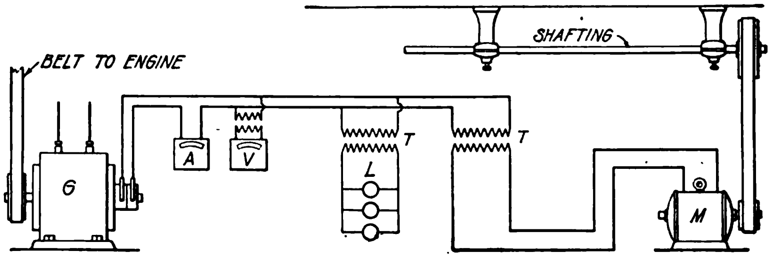


Fig. 16. Diagram of Three-Phase Light and Power Circuit



RESIDENCE OF STANLEY FIELD AT LAKE BLUFF, ILLINOIS
D. H. Burnham and Company, Architects, Chicago

Alternating-current dynamos and transformers are constructed and connected in several ways which differ in regard to the number of partially independent circuits which they supply. An a. c. circuit in which there are but two wires from the generator to the transformer or to lamps or motors is called a ***single-phase*** circuit. Fig. 15 shows the path of the current in a single-phase circuit which includes a generator *G*, switchboard with ammeter *A* and voltmeter *V*, transformers *TT* supplying power to lamps *L* and single-phase motor *M*. Single-phase circuits are used for lighting, both incandescent and arc, and for power.



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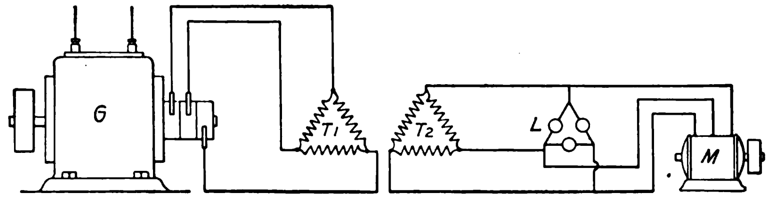
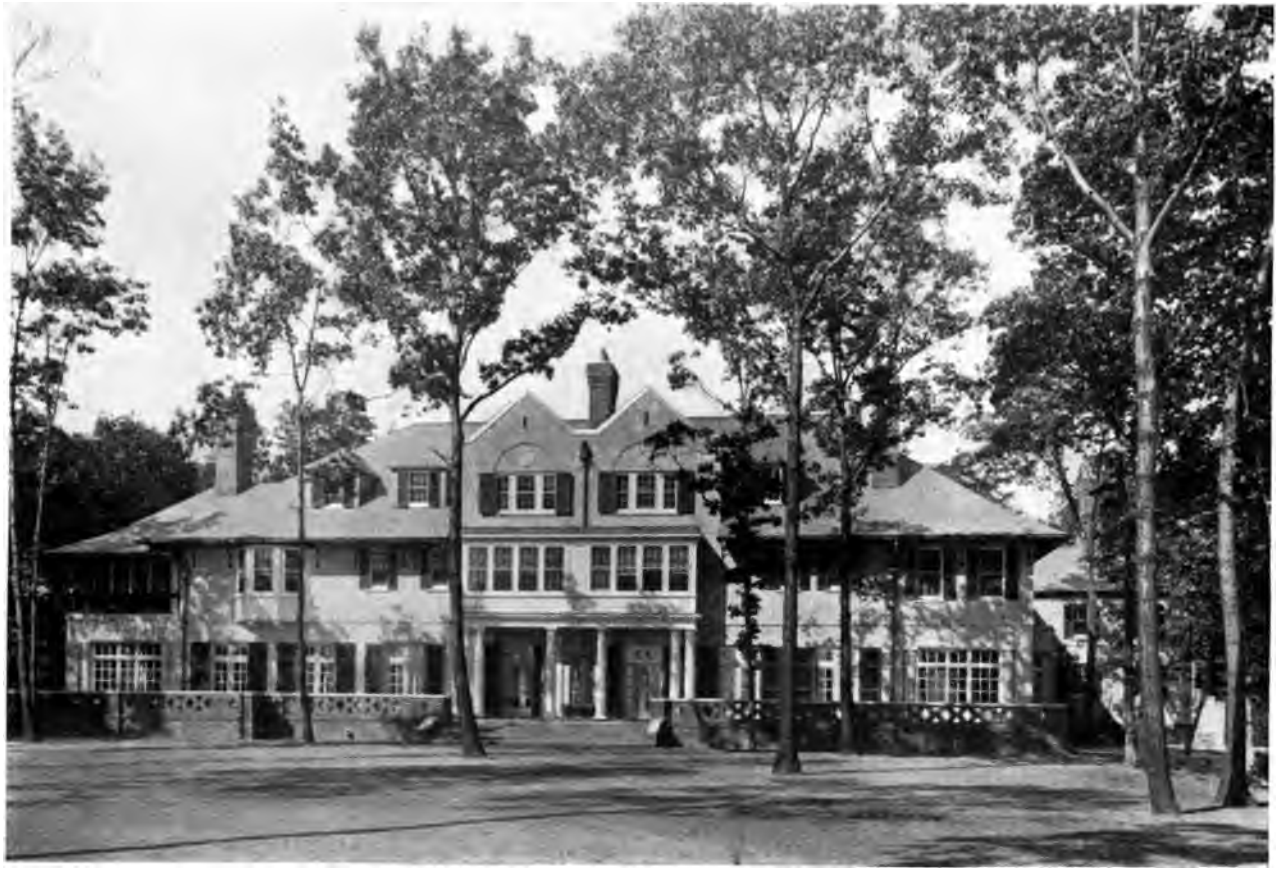


Fig. 16. Diagram of Three-Phase Alternating-Current Circuit



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Essential Parts of Electric Installations. For the general purposes of this book the essential parts of electric installations are as follows:

Generators. Generators include all dynamos and storage batteries. These present the hazards inherent in all machines of any sort which produce or transform large amounts of power.

Cables. Cables and wires used for transmitting electric power are of concern from a fire viewpoint because of the possibility of their becoming overheated by the current, and because failure of the means provided to confine the electric current to them, namely, insulation, may give rise to arcs, *i. e.*, flames from powerful electric sparks or discharges. The rules for safe wiring, therefore, are designed to limit currents on wires to safe values and to insure integrity and reliability in the insulations employed.

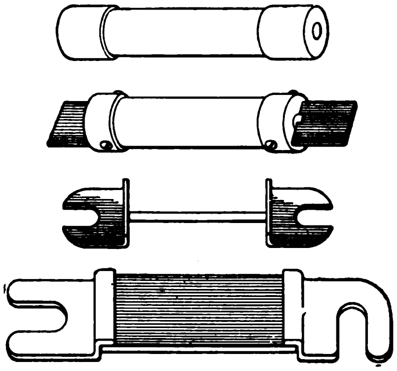
Fig. 17. Forms of Fuses

Closely associated with the conducting wires and cables are those devices which serve to regulate the amounts of current, to open and close electric circuits, or to change the characteristics of currents at or near the apparatus utilizing the power. Of this sort are *rheostats, switches, voltage-regulators, motor-generator sets, rectifiers,* and the very common *alternating-current transformer.* All these must have suitable insulation and mechanical protection, and there must be due protection from the heat or arcs which may be produced in them.

Power-Consuming Devices. The utilization of electric power, as of all power, is always accompanied by the production and dissipation of heat. Power-consuming electric appliances such as motors; all lamps, both arc and incandescent; heaters; and every other appliance using electric current, are, therefore, heat producers to a greater or less extent and must be so treated by the fire-prevention engineer.

Protective Devices. Protective devices are the safety valves of electric circuits. A fuse, Fig. 17, is a portion of an electric circuit purposely made so that it will melt and open the circuit when the current rises to a value which creates dangerous conditions in other parts of the line. The proper design and use of fuses thus involves the two questions of suitable protection to the wires and appliances, and the liability of the fuse itself to cause a fire when it operates.

Circuit Breakers. Circuit breakers, Fig. 18, are automatic switches arranged to open the circuit if currents reach too great values. They thus accomplish mechanically the same results as fuses. As a general principle it may be remembered that high-voltage circuits are more hazardous than low-voltage circuits, because they are more able to injure insulations and to produce arcs across gaps or from one wire to another. Large currents are not more dangerous than small currents so long as they have proportionally larger wires to carry them. In case of failure, however, large currents (many amperes) will cause more trouble. The persistency of an arc and the difficulty of suppressing it when once started, are dependent upon both the voltage and the current (amperes), but it is the voltage which causes arcs to form, as across air gaps or by puncturing insulation on a cable.

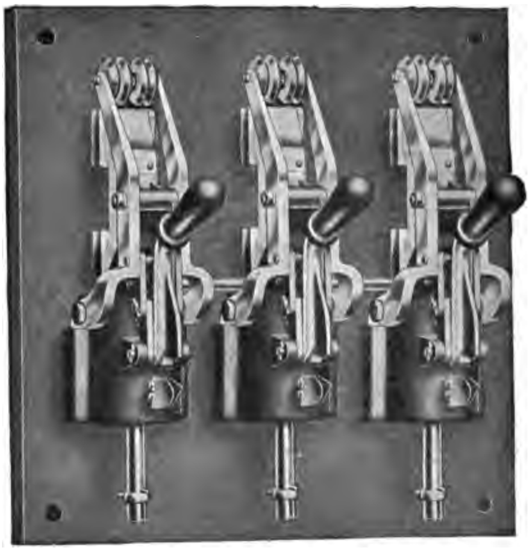

Fig. 18. Automatic Circuit Breaker

The production, transmission, and use of energy are necessarily attended with certain hazards which are in a sense proportionate to the amount of energy employed. The peculiar property of electrical energy is that a failure or accident to electrical appliances often permits a large amount of energy to be suddenly expended as, for example, at an arc or short-circuit, thus developing a great amount of heat,

NATIONAL ELECTRICAL CODE

As the result of the united efforts of insurance, electrical, architectural, manufacturing, and allied interests, there has been developed a comprehensive body of rules governing electrical work. The development and experience leading to these rules covered many years, but in 1897 what is known as the National Electrical Code*, was first issued by the National Board of Fire Underwriters with the approval of a large number of engineering associations of national scope, whose endorsement has given to these rules a standing and reputation unequaled by that of any other body of rules on an engineering topic in this or other countries.

The Code is generally admitted to represent the best opinion on electricity with relation to the fire hazard under the conditions existing in the United States. It is in general use by insurance companies, rating and inspection bureaus and departments, and engineering organizations. It is either adopted unchanged as the official body of rules for cities, or is, in some cases, used as the basis for the rules prescribed by the city government with a few changes or additions which are demanded by peculiar local conditions or which give greater protection against injury to persons than can be prescribed by fire insurance companies, which are, of course, not primarily concerned with the life hazard. These changes are, in nearly every case, of minor importance and consist usually of certain more stringent requirements than have found acceptance as a part of the Code. Few, if any, city rules are less exacting than the Code and nearly all are identical with its provisions.

It should be noted, however, that the Code does not attempt to prescribe the most efficient or economical means of applying electric currents, nor does it formulate engineering rules or practice, except in relation to fire hazards. It is published every two years following a public meeting in New York City at which all proposed changes or additions are thoroughly discussed. These meetings are held under the direction of the Electrical Committee of the National Fire Protection Association, a society the active members of which are insurance boards and bureaus, electric and architectural associations and institutes and other societies of national character. The Code has, therefore, the authority not only of underwriters, but also the indorsement of all the chief associations in the electrical and building industries and professions.

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*The National Electrical Code will hereafter be referred to as the "Code."

Twice every year (April and October) is issued the *List of Electrical Fittings* which gives, under the names of manufacturers, the devices which have been approved for use after samples have been examined and tested according to the construction rules of the code by Underwriters' Laboratories, an institution located in Chicago, Illinois, and maintained by insurance interests for the purpose of making investigations having a bearing on the fire hazard.

In the pages which follow, no attempt will be made to restate *all* of the rules of the Code, but rather to indicate the chief underlying principles of the rules and explain some of the reasons for them.

Copies of the Code can be obtained without cost from any insurance bureau and reference to the Code will be made freely in this book. It is, therefore, assumed that the reader has the Code before him and will refer to it for the official statement of the several rules, and for the relatively less important details not repeated in this text.

POWER STATIONS AND THEIR EQUIPMENT

There are some peculiar hazards present in stations or rooms used for generating electricity aside from those always involved where larger amounts of power are produced and controlled.

In the case of companies furnishing electricity for light and power, the generating and transforming stations are often of large size, and contain apparatus which is very expensive and also of enormous importance for the uninterrupted maintenance of the service they render. Modern practice, therefore, tends toward the housing of such central plants in separate buildings of strictly fireproof construction, and the employment of every resource of engineering skill and experience to prevent fire from causing loss, either by the destruction of the equipment, or by interruption of service resulting therefrom.

The protection against fire in such stations thus becomes one of the chief considerations in the design of the whole plant and passes, therefore, in great measure into the field of the designing engineer. In any modern, well-designed central station the original equipment is usually fairly good from the viewpoint of fire hazard. The chief troubles often result from crowding equipment when it is found necessary to enlarge the capacity of the plant. Ample room for operating and for inspecting is absolutely essential. Accessibility of all portions of electrical equipment, the use of fireproof materials throughout, the installation of protective devices of approved design, and of ample capacity and arrangements, by which any trouble may be readily confined to a limited portion of the equipment, are chief requisites of a central-station equipment from the viewpoint of the electrical fire hazard.

Standard methods of installing generators, switchboards, and all transforming devices, should be followed, but the engineering requirements of special cases and the complexity and variety of such equipments in present-day stations render it manifestly impossible to describe in definite terms the details of construction and installation. In general, generators and motors of themselves present less hazard than the switchboards with the mass of wiring often found on them, the transformers with their charges of inflammable oil, or the large conductors carrying heavy currents and presenting large surfaces of combustible insulations.

Strict compliance with all accepted rules for wiring is of as great importance in central stations as elsewhere, both because of the large values involved, and because of the large amounts of energy to be controlled on the circuits. Central stations, therefore, should never be considered as outside of "Code rules" so far as they apply.

Generators. Generators for either central stations or isolated plants should always be located in a dry, light place as the presence of moisture is apt to injure the machines or may in extreme cases cause short-circuits in leads to the machine. No combustible material should be permitted near a dynamo, and it is desirable that there should be good ventilation to maintain reasonably low temperature, thus increasing the capacity of the machine.

The presence of generators in rooms where any hazardous process is carried on is not to be allowed and it should be remembered that sparks from generator brushes or rings may readily set fire to inflammable gases or to flyings of lint. Generators operating at a potential in excess of 550 volts must have their base frames permanently and effectively grounded. Generators operating at 550 volts or less should be raised above the floor and should preferably be mounted on wood bases (Fig. 19) which insulate the machine frame. Such insulation will prevent a failure of insulation in the machine windings from grounding the system. Such a ground might cause a short circuit if the system became grounded at another point. If the frames are not insulated a reliable ground connection is required in order to give a *good* path for leak currents.

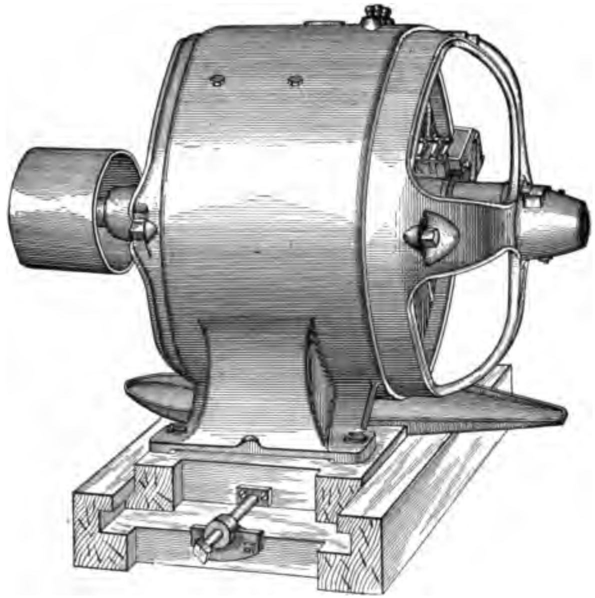
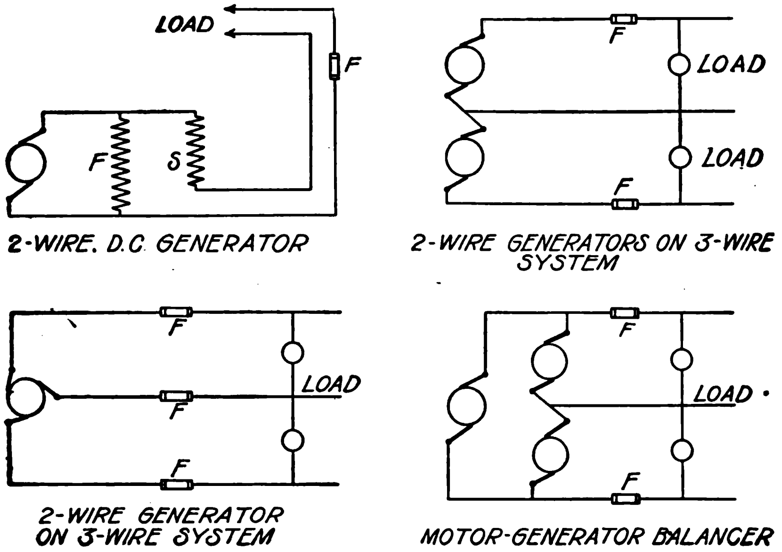


Fig. 19. Generator on Wood Base

In generating plants supplying current to railway power lines, such as trolley and third-rail equipments, the current usually is carried to the trolley or third rail and returns after passing through the car motors by means of the track rails and the ground. All feed wires from such generating stations must be protected at the station by an approved circuit breaker or similar device which will automatically cut off the current from the feed wires if an accidental ground might allow abnormally large currents to pass over the wire.

Dynamos in manufacturing plants are usually installed in the same rooms with the engines which drive them, and such rooms, therefore, present possible hazards from the exposure of wiring to steam piping and to mechanical injuries from whatever work may be done in repairs or alterations of machinery. The most common faults in such locations arise from crowding the electrical equipment into too small and inaccessible locations from a desire to use space either not available for other uses or not especially planned for electrical apparatus. Convenience of operation, cleanliness of surroundings, and a workman-like layout of equipment, all contribute to the maintenance of good fire conditions. The requirements for overload protection at constant-potential generators are shown in the diagram, Fig. 20, where *F* in each figure represents the fuses or circuit breakers required by the Code. These fuses and breakers will usually be located on the main switchboard. This leaves



2-WIRE. D.C. GENERATOR

2-WIRE GENERATORS ON 3-WIRE SYSTEM

2-WIRE GENERATOR ON 3-WIRE SYSTEM

MOTOR-GENERATOR BALANCER

Fig. 20. Diagram Showing Fuse Protection in Various Types of Circuits

the large main cables from generators to switchboard unprotected and for this reason special pains should be taken with their installation since an accident to them might be very serious.

Generator-Room Wiring. All wiring in generator rooms should be done in the most substantial manner, and special attention should be given to simplicity and orderliness of arrangement. All supports for conductors must be very substantial. Fig. 21 shows an excellent example of a large mass of wiring well installed.

All wiring should be readily renewable and accessible. This usually requires either open wiring or some form of conduit. A fiber conduit is largely used for this work and gives good results. The large amount of wire and cable often found in dynamo rooms, together with the large currents carried on the conductors, makes it necessary especially about switchboards to cover the highly inflammable rubber and braided coverings with a tight jacket of some non-combustible material, such as asbestos, to reduce the probability of fire spreading rapidly over all the exposed wiring.

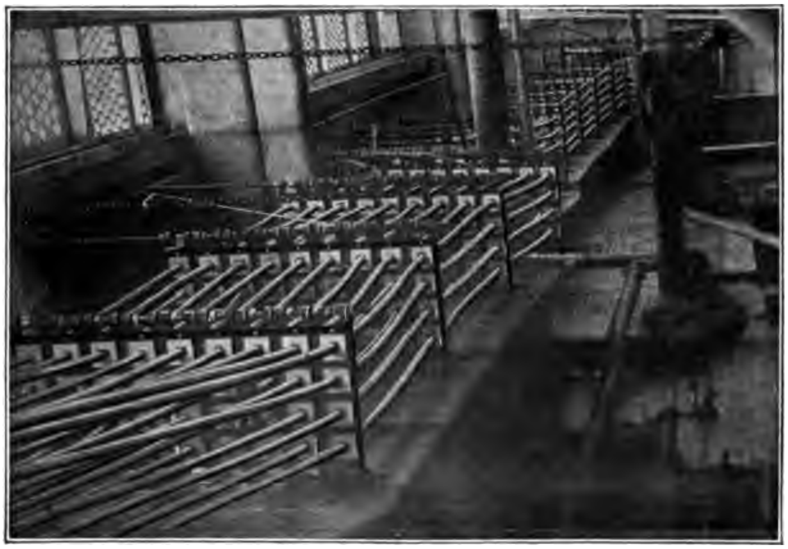


Fig. 21. Example of Large Mass of Wiring Well Installed

Bus bars are usually left bare but there should be as little other bare current-carrying metal as possible.

All conductors should have ample current capacity, and in their installation special care must be given to securing excellent insulation and reliable supports. Due regard should be given to the possibility of injury to conductors by tools, belts, ladders, etc., or by any vibration which may cause a gradual wear on wire coverings.

In general, the requirements of Class C of the Code apply to dynamo-room wiring with such special precautions as are dictated by the large currents to be cared for and the presence of a great number of conductors which may have to be placed rather closely together.

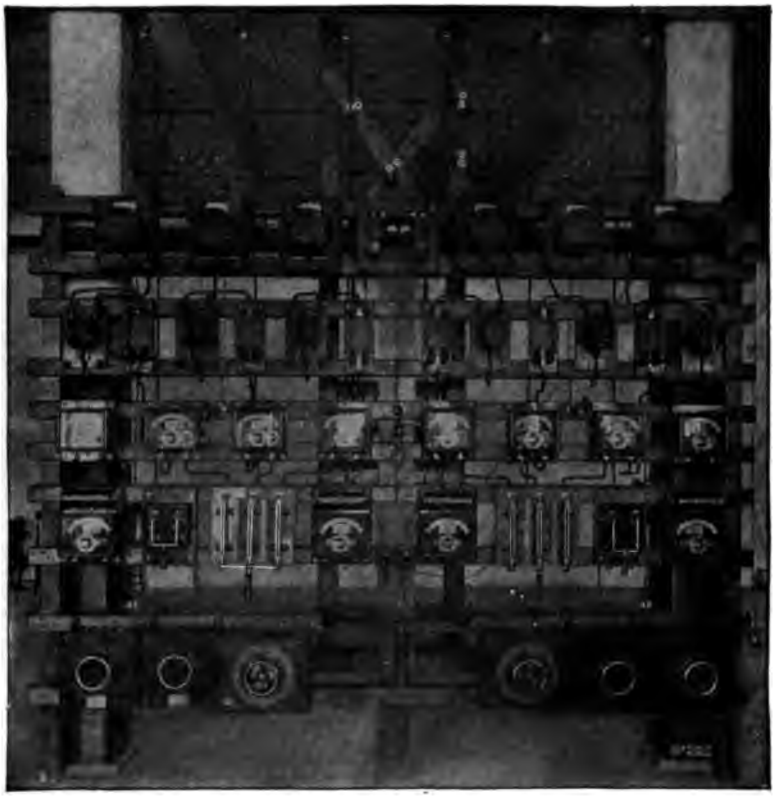


Fig. 22. Old-Style Type of Wood-Frame Switchboard

Switchboards. The danger of fire at switchboards lies in the large number of wires usually concentrated on them, and the use of rheostats, fuses, and other appliances which are possible sources of fire. The switchboard itself should always be of slate marble, or other strong non-combustible insulating material. The old wood racks (see Fig. 22) once used are no longer permitted. Fig. 23 shows a small, well-arranged switchboard. While the front of the switchboard is the operating side, the rear is the part where trouble is more likely to occur. The back of the board should, therefore, be easily accessible and neatness of arrangement and reliable supports for all conductors be imperative. No makeshifts are tolerable on switchboards under any conditions. Fig. 24 shows the back of a board. Every precaution must be taken to keep water or even moisture off switchboards since a short-circuit would be easily started and the result would often be highly disastrous. The Code, Rule 3, gives in detail some requirements for location and care of switchboards, the reasons for which are apparent without further explanation. Fig. 25 shows a large modern switchboard. In general the exact arrangement of parts on switchboards is determined by en-

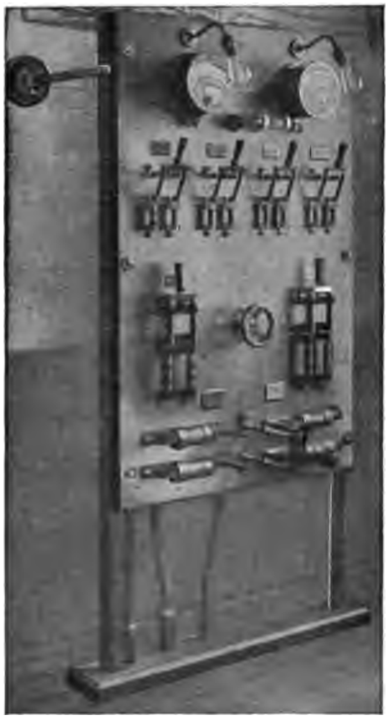


Fig. 23.* Approved Type of Small Switchboard

Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.

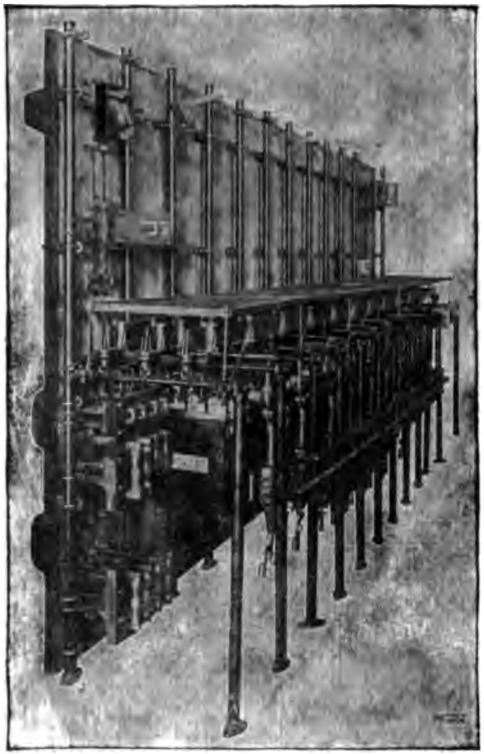


Fig. 24. Back View of Well-Arranged Modern Switchboard

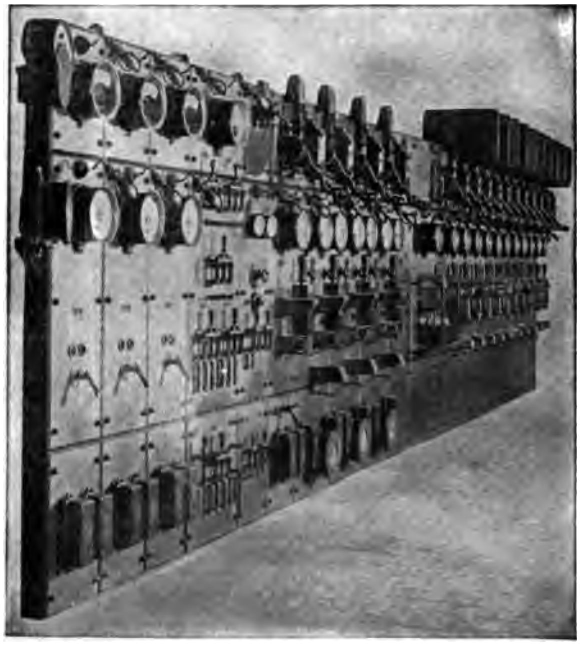


Fig. 25. Front View of Large Modern Switchboard

gineering and operating requirements, and the interest, from the viewpoint of fire, centers in the protection of conductors and the location of board and instruments to reduce the probability of fire spreading from the board to the other parts of the building. Orderliness and cleanliness should be insisted upon.

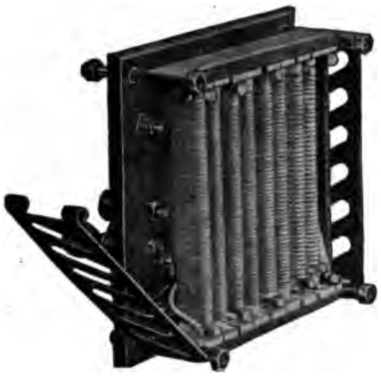


Fig. 26. Interior View of Small Starting Rheostat

Resistance Boxes or Rheostats. These are used in a great variety of sizes and designs with dynamos and motors and at switchboards. They may be mounted either on the machines or switchboards or separately, but in every case they must be considered as "stoves" and liable to become "red-hot." The fact that they do not become hot when used under normal conditions is not to be considered as in any way lessening the requirements for protection.

A burn-out of a rheostat may result in a mass of flames from the numerous wires, usually contained in or leading to the device, and there may be drops or spurts of melted solder or other metal. Fig. 26 shows the interior of a small starting rheostat.

All resistance devices used for starting, regulating, and controlling machines are to be classed as "resistances" in the intent of the Rules, and so in general are all devices or parts of devices where coils of wire, iron grids, or other similar objects are made parts of the circuit.

Lightning Arresters. The purpose of these devices is to prevent lightning, or external high-voltage currents from foreign circuits, entering the station and there causing fire or damaging machinery and instruments. Lightning cannot be "stopped" but may be *diverted* to the earth. A large variety of lightning arresters are on the market but they are all designed to afford a path by which discharges may pass to "ground" instead of into the station apparatus and to prevent so far as possible the normal currents on the lines from following this path. The operation of many lightning arresters is accompanied by sparks which may in severe cases assume the size of powerful arcs. The location of these devices away from all combustible material is thus imperative. They are often installed in separate buildings with other emergency appliances.

The full discussion of lightning-arrester construction, operation, and installation is impracticable in this book. Suitable location, the running of connections in straight lines with the fewest possible bends, the use for ground wires of copper wire not smaller than No. 6, and especially the securing of permanently good ground connections are the chief considerations. Two separate ground connections are often desirable. Fig. 27 shows a type of electrolytic lightning arrester for 7,000 volts maximum potential to be used on three-phase circuits.

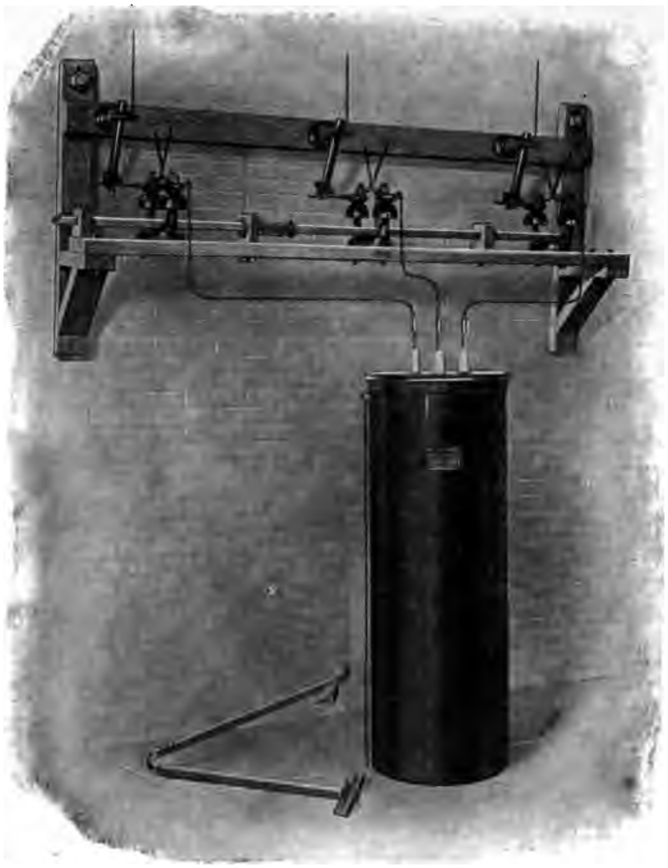


Fig. 27. Electrolytic Lightning Arrester for 7,000 Volts

Ground Detectors and Tests. Except where circuits are intentionally and permanently grounded, a leak to "ground" may be the cause of arcs at some points in the system which may be dangerous. By "ground" is to be understood the earth, walls or floors of masonry, pipes of any kind, iron beams or floors and the like. It is, therefore, required that suitable instruments and circuits be provided to indicate either continuously, or by frequent tests, whether there are such ground connections which would indicate a failure of some insulation. If such a failure is shown by the detector the trouble can usually be located and repaired before injury is done.

Ground detectors may take the form of special instruments on the switchboard or of arrangements of switches with lamps or voltmeters which can be used to test the insulation of each side of each circuit in turn. The connections should be such that the detector cannot be left out of circuit. For the various arrangements of ground detectors reference must be made to the standard electrical treatises.

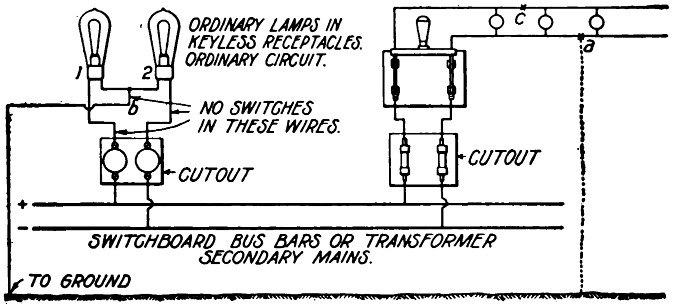

ORDINARY LAMPS IN KEYLESS RECEPTACLES. ORDINARY CIRCUIT.
1
2
b
NO SWITCHES IN THESE WIRES.
CUTOUT
c
a
CUTOUT
+
−
SWITCHBOARD BUS BARS OR TRANSFORMER SECONDARY MAINS.
TO GROUND

Fig. 28. Wiring Diagram for Ground Detector on Any Two-Wire Low-Voltage System

Attention may be called to the following points which are frequently neglected:

(1) Lamp receptacles should be keyless and any switches in the detector circuits should be so connected that the detector will continuously give an indication on at least one side of the circuit.

(2) The wires should always be protected by small fuses where they connect to the bus bars.

(3) If the detector is of a type depending on relative brightness of two lamps, the lamps should be very close together.

(4) Special care should be taken to secure excellent ground connection for the ground wire.

The accompanying diagram, Fig. 28, shows a very good and simple detector for any two-wire low-voltage system, and is typical of many in use. (The diagram and description are taken from a publication of the Associated Mutual Fire Insurance Companies.)

The lamp for the detector should be of the same candle power and voltage, the voltage being about the same as that of the regular lamps in the plant, and two lamps should be selected which, when connected in series, burn with equal brilliancy. Although somewhat greater sensitiveness can be obtained with low-candle-power lamps, such as 8 c. p. for example, it is believed in general to be preferable to use lamps of the same candle power as those throughout the plant, as then a burned-out or broken-detector lamp can be immediately replaced by a good lamp from the regular stock, thus avoiding the necessity of keeping on hand a few spare special lamps.

The detector lamps, being two in series across the proper voltage for one lamp, burn only dimly. If, however, a ground occurs on any circuit, as at *a*, the current from the positive bus bar through lamp No. 1 divides on reaching *b*, instead of all going through lamp No. 2, as it did when there was no ground. Part now goes down the ground wire and through the ground to *a*, as indicated by the broken line, and thence through the wires to the negative bus bar. This reduces the resistance from *b* to the negative bus bar, and, therefore, more current flows through lamp No. 1 than before, while less current flows through lamp No. 2. Lamp No. 1 consequently brightens and lamp No. 2 dims. If the ground had occurred at *c* instead of *a*, lamp No. 2 would have brightened and lamp No. 1 dimmed. This detector, while not able to indicate extremely small leaks, will show any leak that is likely to be dangerous from a fire standpoint.

Motors. Electric motors are very generally used in manufacturing plants of all sorts and their use is still rapidly increasing. They are also used very extensively for elevators, cranes, and for an infinite variety of uses in all classes of buildings. Recently portable motors of small size have come into very general use for drills, and other portable tools, vacuum cleaners, washing machines, and scores of other purposes where their cleanliness, economy, and adaptability recommends them. These portable types of motors, however, do not in general come under the rules prescribed for stationary machines, though their use involves similar hazards and some others peculiar to themselves. These will be discussed later.

In general the same precautions should be taken with motors as with generators. Dry, clean, well-lighted locations should be chosen for them. It is a very common fault to install a motor in a space too small for it, or in a place where rubbish and dirt are allowed to accumulate. The fact that modern motors are very sturdy machines, and will continue to work even when neglected and abused, encourages carelessness in maintenance which often results in hazardous conditions. Except where unavoidable, motors must never be located in the vicinity of combustibles, in wet places, or in very dusty or dirty places. When such locations are unavoidable, an "enclosed" type of motor should be used, or a special room, Fig. 29, should be provided. Many modern types of alternating-current motors have no exposed live parts and do not have commutators or brushes and are, therefore, well suited to dusty or linty places. Fig. 30 shows a rough commutator of a motor. It is evident that as the commutator revolves, the brush which carries the main motor current will not fit well at all points and, therefore, sparking will result. In extreme cases this sparking may be dangerous, especially in dusty places or where inflammable gases are present. Where motors are used, not of enclosed types with brushes, commutators or slip rings, where sparking may occur, special enclosures should be provided. The installation of motors on ceilings, Fig. 31, or built in as parts of the special machines which they drive, often affords both the neatest

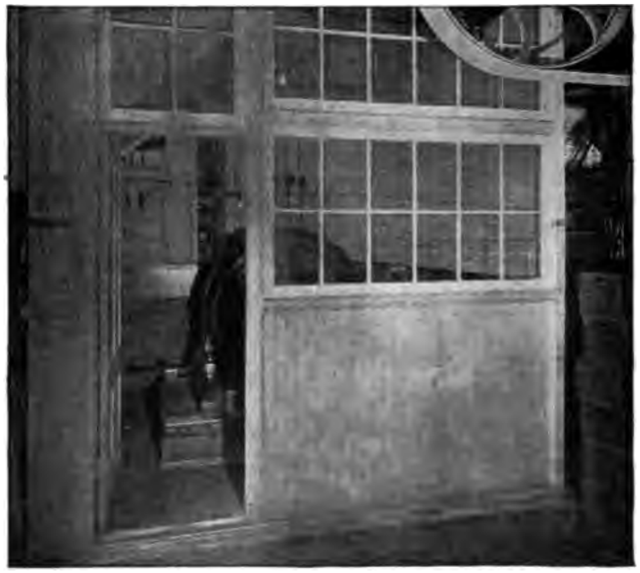


Fig. 29.* Approved Housing for Motor in Bad Location

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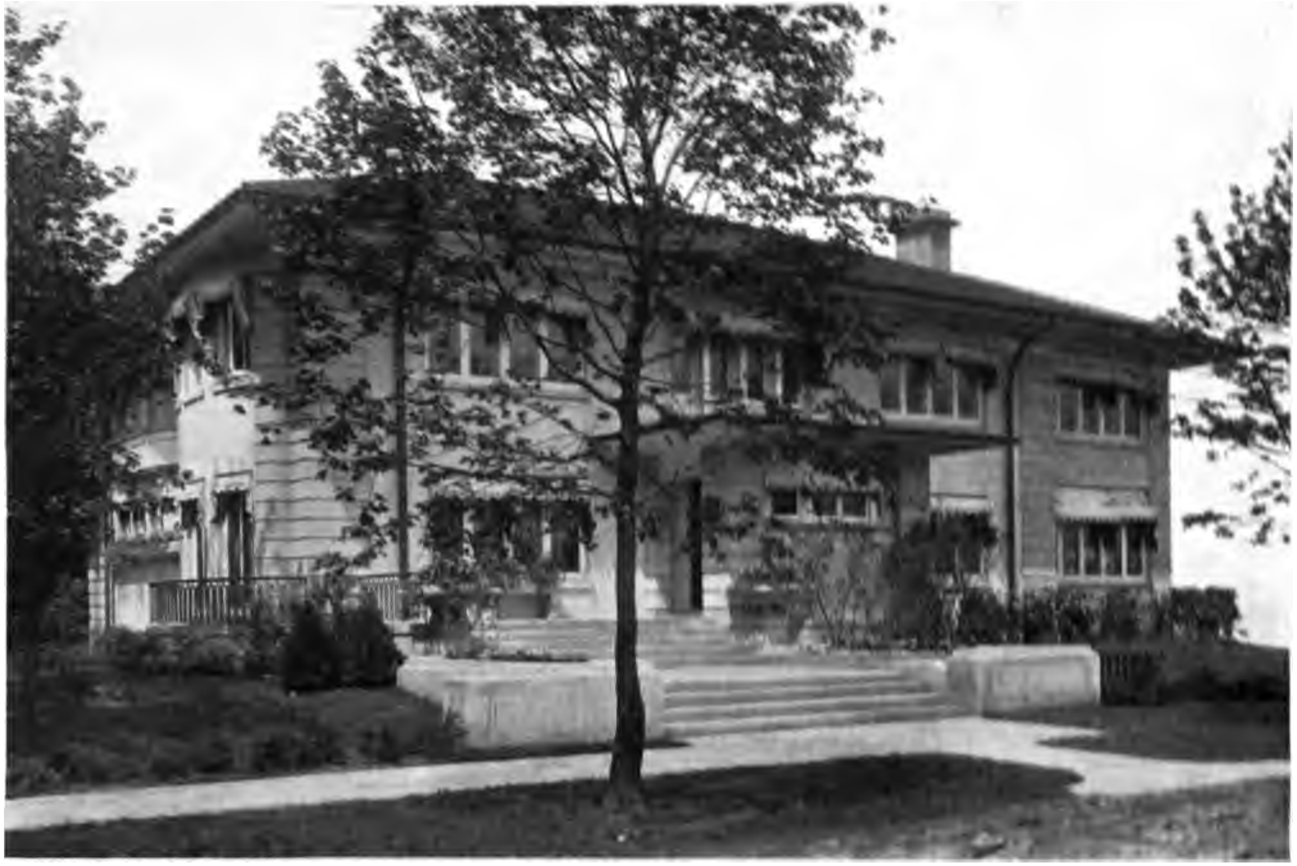
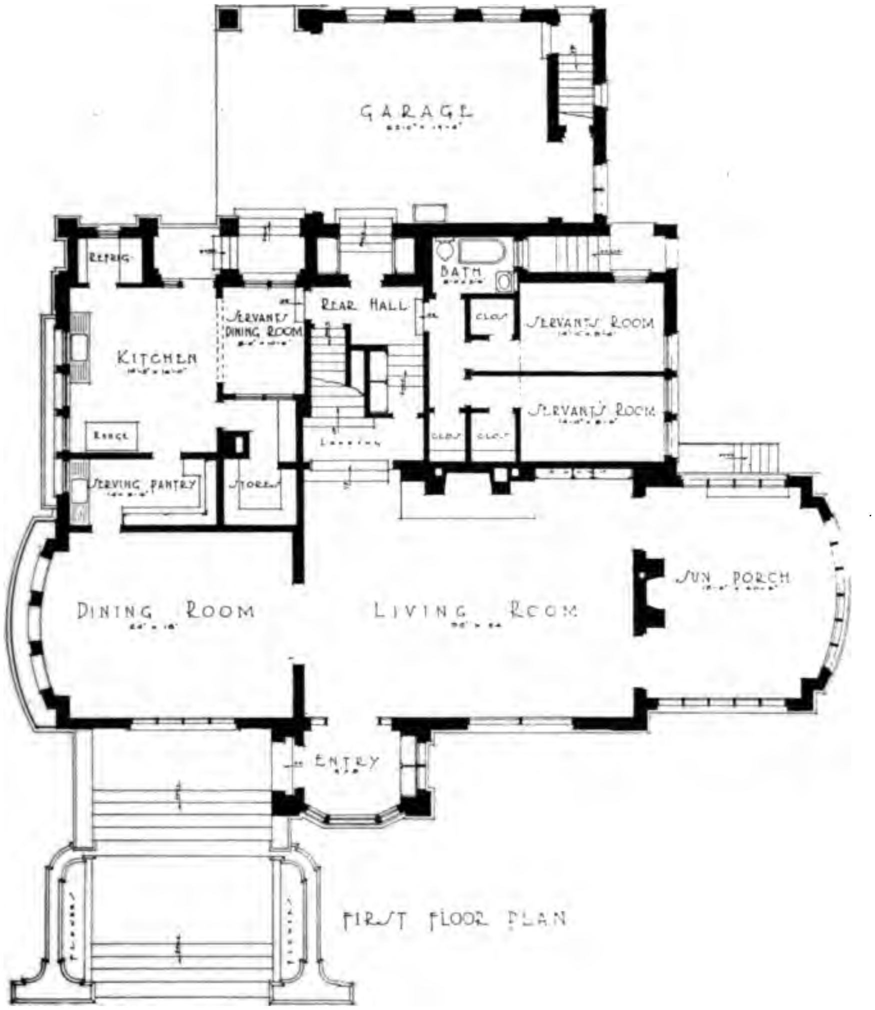
*Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.



RESIDENCE OF H. M. STEVENSON, SHERIDAN ROAD, CHICAGO
George W. Maher, Architect, Chicago
For floor plans see opposite page



FIRST FLOOR PLAN OF H. M. STEVENSON RESIDENCE ON SHERIDAN ROAD, CHICAGO
George W. Maher, Architect, Chicago
For exterior view see opposite page

and the safest arrangement. Motors operating at voltages over 550 volts require special precautions in respect to wiring leading to them. Motors for less than 550 volts are wired according to the general rules for low-potential systems.

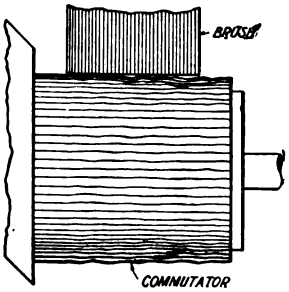


Fig. 30. Rough Motor Commutator Increases Sparking

Wiring to Motors. The supply leads to motors must be of a size to carry at least 25 per cent more current than that for which the motor is rated. This applies to all types of motors both d. c. and a. c. and is required even though the motor is not actually being used for its full load. This is called for to provide for the currents required to start the motor which are almost always greater than the current needed for continuous full load running, and also to safeguard the motor against exceptionally heavy currents, thus providing a margin of safety at all times.

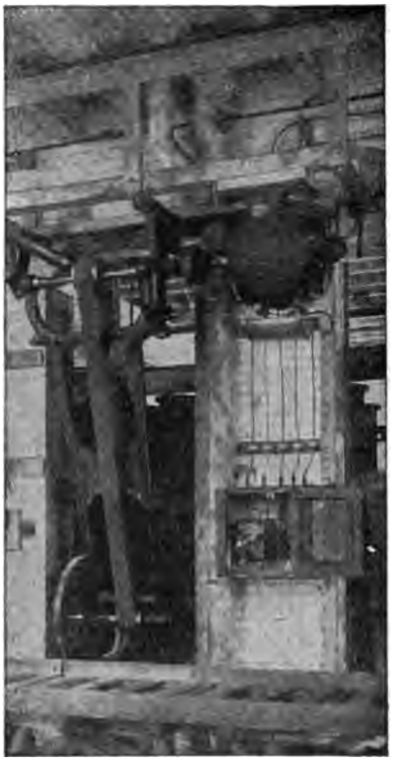


Fig. 31.* Approved Ceiling Mounting for Motor

Wiring for Direct-Current Motors. The Code prescribes the safe carrying capacity of wires of different sizes, Page 65. Thus if a direct-current motor requires 44 amperes when working under full load, the lead wire must be of such size as to carry 55 amperes. A reference to Rule 18 shows that this will call for a No. 6 wire.

The factors which are involved in the determination of the proper size of leads to direct-current motors may be summed up as follows:

Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.

TABLE I

Size of Wires for Direct-Current Motors

Horse Power	110 VOLTS			220 VOLTS			500 VOLTS
	Full Load Current	Size of Wire Mains	Size of Wire Branches	Full Load Current	Size of Wire Mains	Size of Wire Branches	Open
1	8	14	14	4	14	14	14
2	15	12	10	8	14	14	14
3	23	10	8	12	14	12	14
4	30	8	6	15	12	10	14
5	38	6	6	19	10	10	14
7.5	56	4	3	28	8	6	14
10	75	3	1	38	6	6	12
12.5	94	1	0	47	5	4	10
15	113	0	00	56	4	3	10
17.5	131	00	000	65	4	2	8
20	150	00	0000	75	3	1	8
25	188	0000	c. m. 250	94	1	0	6
30	225	c. m. 250	350	113	0	00	5
35	263	300	400	131	00	000	4
40	300	350	500	150	00	0000	3
45	338	400	600	169	000	c. m. 250	
50	375	500	700	188	0000	250	1

Column headed "Size of Wire, Branches" gives size of wires for branches and for mains supplying one motor and is based on the 25% overload demanded by the rule.

Column headed "Size of Wire, Mains" gives size of wire to be used for mains, but in no case must the size of these mains be less than that required for the 25% overload on the largest motor such mains supply.

The question of drop is not taken into consideration in these tables.

E = volts required by motor
k = efficiency of motor
h.p. = rated horse-power of motor

Then if I = current in amperes at full load and at the given voltage

$$I = \frac{\text{h.p.} \times 746}{E \times k}$$

When I is found, a reference to the Wire Capacity Table, Page 65, will show what size of wire is required for current 25 per cent in excess of I.

In Table I are given the sizes of conductors in Brown and Sharpe gauge required for direct-current motors for 110 and 220 volts for different sized motors from 1 up to 50 horsepower. The table is taken from the rules of the City of Chicago; other cities have slightly different rules.

TABLE II

Sizes of Wires for Alternating-Current Motors

SINGLE PHASE

Horse Power	110 VOLTS		220 VOLTS	
	Full Load Current	Size of Wire	Full Load Current	Size of Wire
1	12	12	6	14
2	23	8	11	12
3	33	4	16	10
4	44	4	22	8
5	53	2	26	6

Size of Wires for Three-Phase Motors

THREE PHASE

Horse Power	220 VOLTS				440 VOLTS	
	Full Load Current	Size of Wire Mains	Size of Wire Branches	Full Load Current	Size of Wire Mains	Size of Wire Branches
1	3	14	14	2	14	14
2	5	14	14	3	14	14
3	8	14	12	4	14	14
4	10	14	12	5	14	14
5	13	12	10	6	14	14
7.5	19	10	8	10	14	12
10	26	8	6	13	12	10
12.5	32	8	5	16	12	10
15	38	6	4	19	10	8
17.5	45	6	3	22	10	8
20	51	5	3	26	8	6
25	64	4	1	32	8	5
30	77	3	0	38	6	4
35	90	2	00	45	6	3
40	102	1	00	51	5	3
45	115	0	000	58	4	2
50	128	0	0000	64	4	1

Column headed "Size of Wire, Branches" gives size of wire for branches and for mains supplying one motor and is based on the 50% overload demanded by the rule.

Column headed "Size of Wire, Mains" gives size of wire to be used for mains, but in no case must the size of these mains be less than that required for the 50% overload on the largest motor such main supplies.

The question of drop is not taken into consideration in these tables.

Wiring for Alternating-Current Motors. The calculations for proper sizes of wires for alternating-current motors, are somewhat more complicated than for direct-current motors.

Table II gives the wire sizes prescribed by the rules of the Department of Electricity of the City of Chicago. Somewhat different values are, however, in use in other places and no universally accepted rule has yet been developed.

Switches and Protective Devices with Motors. Every motor of over ¼ horse-power must be protected by fuses or circuit breakers, and controlled by a switch; and all of these must be located within sight of the motor, and be arranged so as to open and to protect all the wires. An automatic circuit breaker which will disconnect all the wires of the circuit is considered the equivalent of both the fuses and the switch.

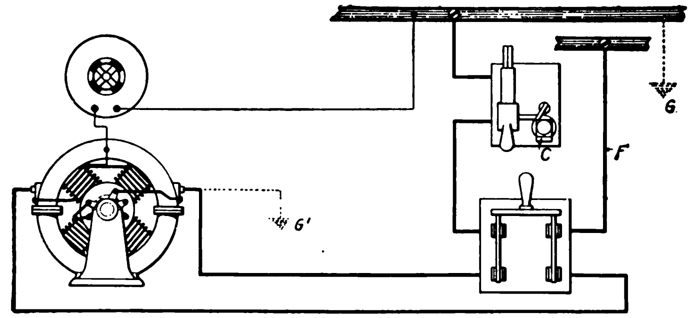


Fig. 32. Wiring Diagram of Motor Circuit Showing Inadequate Fuse Protection

The chief purpose of the fuses is to protect the motor and especially the wiring to it from overloads resulting from accidents to the motor or from the excessive current which will flow if an attempt is made to start the motor when it is for any reason unable to start and attain its proper speed. The fuses must, therefore, always be of such size as to blow with currents not in excess of the specified carrying capacity of the supply wires. Circuit breakers must not be set more than 30 per cent above the carrying capacity of the wire unless fuses are also used. Where rubber-covered wire is used for the leads or branches of alternating-current motors of the types requiring large starting currents, the wire may be protected in accordance with Table III on page 65, except when circuit breakers are installed which are equipped with time element devices.

Each wire of motor circuits, except on main switchboard or when otherwise subject to competent supervision, must be protected by an approved fuse whether automatic overload circuit breakers are installed or not. Single-phase motors may have one side protected by an approved automatic overload circuit breaker only if the other side is protected by an approved fuse.

For wiring circuits which have a maximum capacity greater than that for which enclosed fuses are approved, automatic overload circuit breakers alone will be approved.

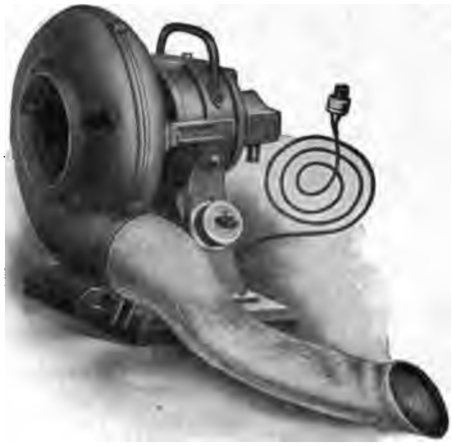


Fig. 33. Small Ventilating Outfit to be Connected to Lamp Socket

The switch at a motor is required so that the line can be readily disconnected from the motor when the latter is not in use or in case of accident. On two-wire systems, a double-pole switch is required, on three-wire, a triple-pole. If a circuit breaker is used without fuses it must be of a type which will protect the motor under all circumstances. Thus in Fig. 32 the single-coil circuit breaker does *not* comply with the rule, since, if a ground should occur on the main at *G* and another on the motor at G^1, the coil *C* of the circuit breaker would be cut out of the circuit and the breaker would fail to operate, for no provision is made to open the other line. In this case a fuse of proper size should be installed at *F* or a circuit breaker having a trip coil in *each side* should be substituted for the fuse and breaker shown in Fig. 32. If the circuit breaker takes the place of the switch at the motor it must be such that one line cannot be opened without opening also all the others.

Motors of ¼ h.p. or less may be connected to circuits less than 300 volts in the same way as incandescent lamps, provided the proper fuses are used in the branches supplying the power to them. Such motors, illustrated by desk-fan motors and all portable motors of small size, do not usually require starting rheostats. Fig. 33 shows a small ventilating outfit to be connected to a lamp socket.

Rheostats with Motors. Rheostats are used with motors for starting them and for controlling their speed. They should always be regarded as sources of heat and installed accordingly. Fig. 34 shows a common type of motor-starting rheostat. Such rheostats (called motor starters) need to be in the circuit for only the very short time usually required to bring the motor up to speed and, therefore, they are usually so designed to carry the necessary current for only this brief period. Such motor starters, if left with current passing through their coils or grids for longer periods, will become very hot and may burn out. The manner in which a simple motor starter is connected is shown in Fig. 35 when *A* represents the armature of the motor, *M* the field coil or electromagnet of the motor and *R* the resistance coils in the starter rheostat box. The required fuses and switch are shown at *FF* and *S*. In this design the starter, fuses, and switch are all mounted on a single slate base. To start the motor, the switch *S* is first closed and the handle *H* is slowly moved from *O* to the position shown in the diagram. It will be seen that the resistance *R* during the process of starting serves to limit the current supplied to the motor armature, which would otherwise, until the motor came up to speed, be excessively large. When the handle has reached the position shown, the resistance is all cut out of the circuit. A rheostat of this sort cannot be used safely except to *start* a motor of the proper size for it. The resistances will get excessively hot if *H* is allowed to remain at any intermediate point.

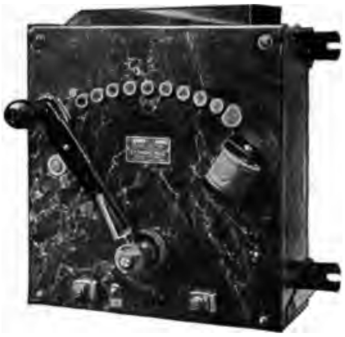


Fig. 34. Common Type of Motor Rheostat

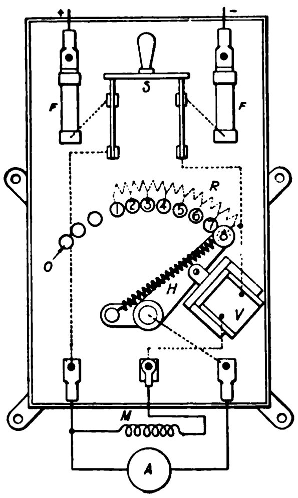


Fig. 35. Starting Rheostat Wiring Diagram

Motor starters for d. c. motors must, therefore, be made so that a spring or other device will return the lever to the "off" position in case the operator attempts to leave the starter with current passing through its resistance coils. This is because these coils are not designed for this continuous duty. When, however, the lever has been moved clear across to its final position, it is held there by a small electromagnet (V in Fig. 35) but in this position the connections have been shifted so that the resistance coils are no longer in the circuit. If now it should happen that the supply of current should fail, the electromagnet (called the *no-voltage release*) will release the lever which will fly back to the original "off" position. Then when the supply is re-established the motor will not be injured by starting too suddenly, or by the severe arcing at the motor commutator.

Since a. c. motors usually have no commutators and are less liable to injury from sudden starting, a no-voltage release is not required in a. c. starters.

A somewhat different device called an *autostarter, potential starter*, or *compensator*, is often used for starting a. c. motors. It is a form of transformer which allows only a portion of the line voltages to be applied to the motor until it is well started. Autostarters are to be regarded as sources of heat, and much the same precautions are necessary as with ordinary starters containing wire coils or iron grids. If they contain oil-immersed switches or coils, the oil adds a further hazard on becoming overheated or spattered about. Fig. 36 shows the interior of a compensator.

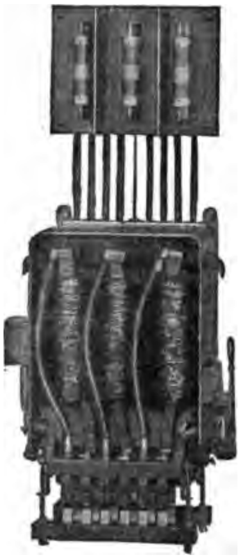


Fig. 36. Interior View of Compensator

In general, motor starters, either d. c. or a. c., involve both the hazards of switches and those of possibly overheated coils of wire or other parts, and must be treated accordingly.

Another class of rheostats includes those which are intended for regulating the speed of motors and generators. They are necessarily used continuously whenever the machine is running and, therefore, must be proportioned so that their coils or other resistances will not become overheated, even when the necessary current traverses them for hours at a time. Fig. 37 shows a large rheostat of this type. Among these rheostats are classed field rheostats for dynamos, controllers for motors (as distinguished from motor starters), theater lamp dimmers, and, in fact, *all* rheostats or resistances which are required to be continually in the circuit. Some motor starters are designed to serve also as controllers and may have two sets of resistances, one for starting only and the other for continuous duty in varying the speed of the motor. These are especially useful in connection with machine tools and similar apparatus.

Special forms of rheostats having their resistances so enclosed that a burn-out will not cause sparks, are required in dusty or linty places, such as flour mills, various textile mills, etc. If such specially protected starters are not supplied, the starting apparatus should be in special rooms where the dust or lint can be kept out.

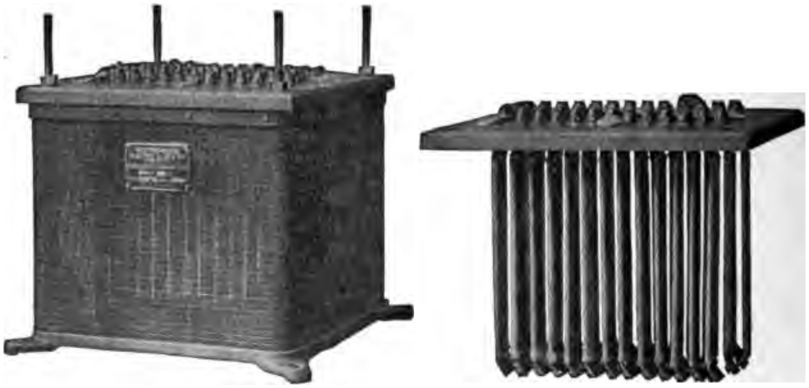


Fig. 37. Closed and Open Views of Large Rheostat for Continuous Service

The dangers to be guarded against in all rheostats of every type arise from the fact that these appliances must from their very nature be sources of heat. By liberal design and good ventilation the *temperatures* can be kept low; but all rheostats should be installed with the idea that they may become overheated by failure or misuse, Fig. 38. The large amount of insulated wire often used, and the oil in which parts are sometimes immersed, may furnish a considerable amount of fuel, and in severe burn-outs, flames may result and molten metal be ejected. A large amount of smoke usually accompanies a burn-out of a rheostat.

Storage Batteries. Batteries of large size are now in common use. These are practically always storage batteries, that is, batteries which are recharged by having current from a generator supplied to them from time to time. What are called primary batteries, that is cells in which there is a chemical action which sets up a current without any machine being used to charge and recharge

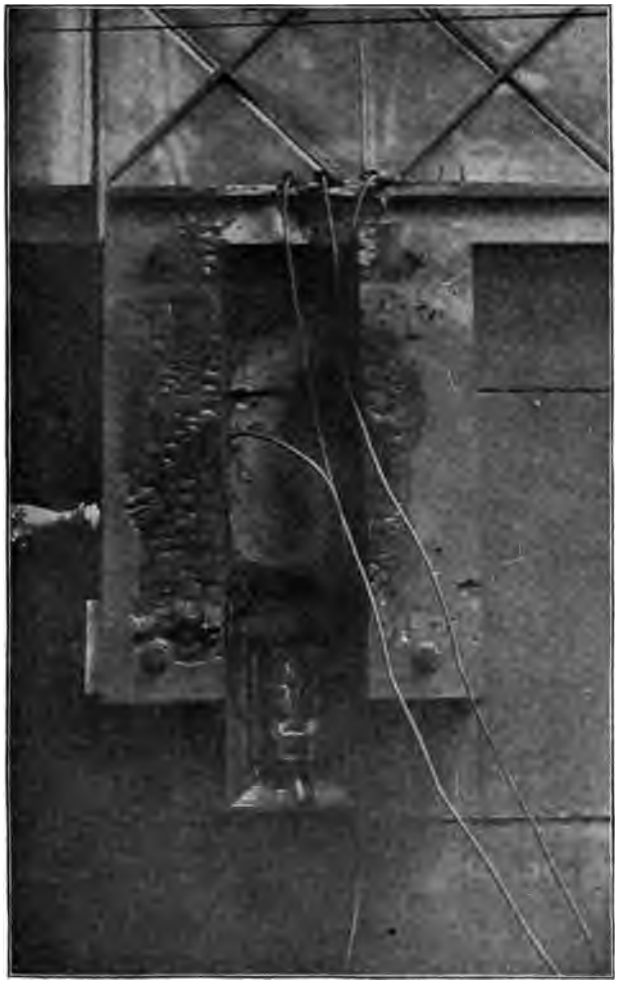


Fig. 38. Example of Badly Installed Rheostat and Switch

them, are sometimes of large size, and develop fairly high voltages. They are, however, used chiefly for telegraphs and other signaling work and need not often come under the supervision of underwriters or fire-protection engineers.

Storage cells, however, where they are capable of developing the same voltage (100 to 600 volts not uncommon) require the same general precautions as dynamos or motors since they produce like amounts of energy. Furthermore, it is a property of such batteries that in case of a short-circuit they can for a short time supply very large currents, far larger than they are normally called upon to supply. Thus they may be termed reservoirs of energy, capable of producing trouble if their output is not properly controlled.

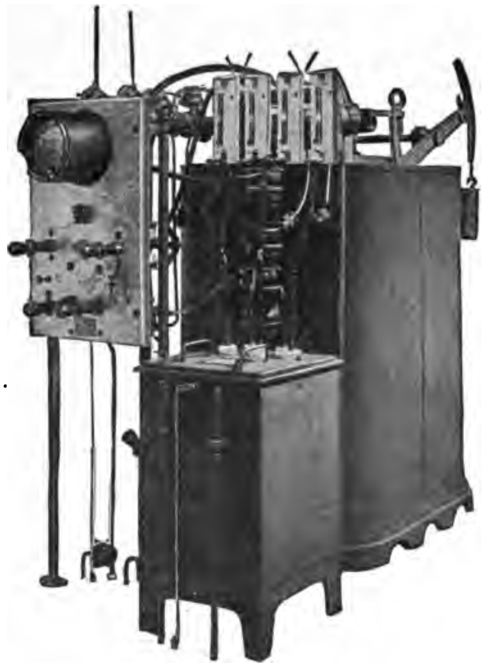


Fig. 39. General Electric Arc Lighting Transformer with Series Rectifier

Storage battery rooms should be thoroughly ventilated. The action of the current in charging the battery, liberates at times large quantities of hydrogen and oxygen, and if these should accumulate in the right proportions, they would form an explosive mixture which might be exploded by any accidental spark.

The water and acid used about storage batteries make it necessary to provide especially good insulation. The battery jars are best mounted on glass strips set on special porcelain insulators. The usual precautions for rooms where acid fumes exist should be taken in battery room wiring, and metal parts must not be such as to be affected by corrosion, since a decrease of the cross-section area of any current-carrying part may ultimately reduce the metal to a degree that will cause overheating or, in case of an actual break, a dangerous arc.

Transformers. In central or substations or in large power rooms of isolated plants or factories, the chief point in the installation of transformers is the provision for preventing injury from the fire resulting from burning out of the coils or, in the case of oil-filled cases, from the boiling over of the oil. These effects are, of course, produced only from some accident to the apparatus or circuits, but transformer fires are peculiarly difficult to fight, and the oil and the insulations on the windings produce, at high temperature, large volumes of smoke which may damage goods in other parts of the building than the transformer room itself, or which might be mistaken for a fire and result in water being thrown into the building entailing a heavy "water loss." Transformers should always be located in clean, dry places with ample space about them. Fig. 39 shows a General Electric constant-current arc-lighting transformer with series rectifier outfit for 4-ampere 50-light system.

OUTSIDE WORK

Defects or failure of electric light or power circuits outside of buildings, as on poles or over the roofs or walls of buildings, may become the cause of fire by setting up abnormal conditions in appliances connected to them, by setting fire, either by overheating or arcing, to buildings on which they are supported, or especially by *crosses*. By a *cross* is meant an accidental touching by wires of one circuit or line with those of another line. By such accidental contacts lines may become charged with a higher voltage than they or their appliances are suited for. Thus a cross between a 2,200-volt arc-light wire and a 110-volt house-lighting circuit may cause current from the 2,200-volt circuit to pass into one or more houses where it will perhaps blow fuses with an explosive action, or cause very dangerous arcs as it passes to the ground through some defective insulation, Fig. 40. Similarly it is very dangerous for an ordinary lighting circuit to become crossed with a telephone wire, since the insulation and carrying capacity of telephone wiring is not such as to resist the effects which might be produced. For reasons such as these, outside wiring has a definite relation to fire hazard even in buildings.

Wiring. In very many cities and towns insufficient attention was paid to outside wiring until the streets and alleys became crowded with circuits of all sorts, each put up as was cheapest or most convenient at the time it was constructed. Where some of these circuits are of high power and high voltage exceedingly dangerous conditions exist, and the hazard may be extended over large areas remote from the place where actual failure occurs, since the resulting accidental currents may pass over any of the lines involved to buildings at considerable distances. The efforts of fire-protection engineers and insurance interests should be directed toward the correction of faulty outside wiring conditions, which if neglected are bound to

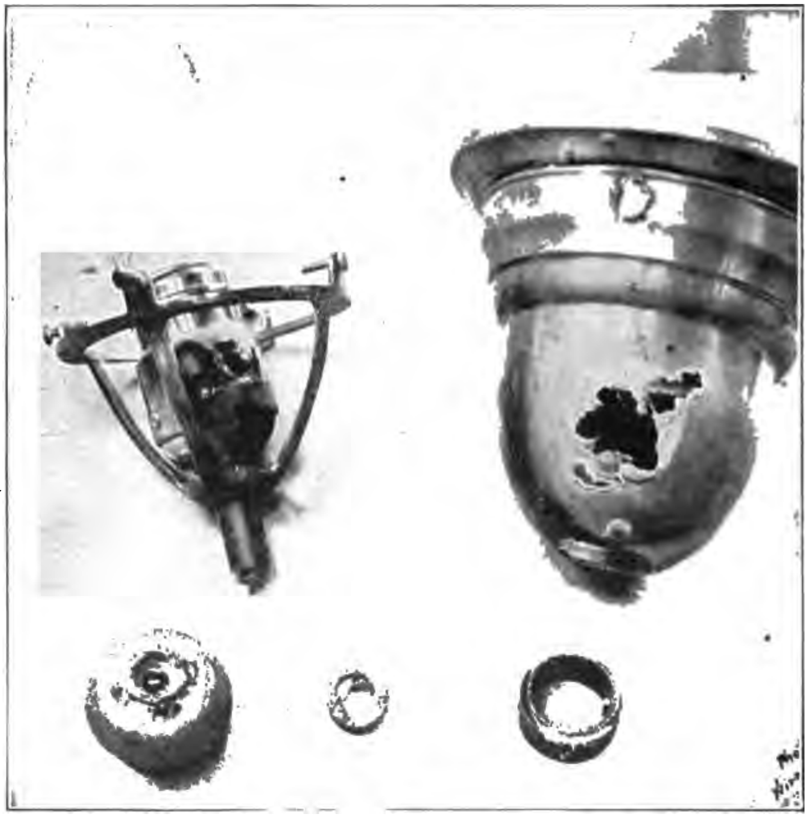


Fig. 10. Result of Cross Between 2200-Volt Lighting Circuit and 110-Volt House Circuit

become progressively worse and constitute a serious menace to lives and property.

Where an insured property is clearly jeopardized by outdoor wiring, excellent electrical conditions indoors can at best afford only a partial safeguard, and fire-protection engineering should apply itself to remove the defects out-of-doors as well as in.

Underground System. The placing of electric wires underground, especially where low voltage and signal circuits are carried in separate conduit systems, affords the most thorough solution of the hazards of town and city wiring. Underground wires are, of course, less liable to accidents of weather and storm, and are, therefore, preferred by operating companies although the expense of putting wires underground often prevents or postpones a change. Legislation prescribing a gradual change, a certain amount of wiring being put underground each year, has often produced results without undue hardship to electric companies. However, there are certain well defined precautions and standard methods for outside work which can reduce hazards to a great extent.

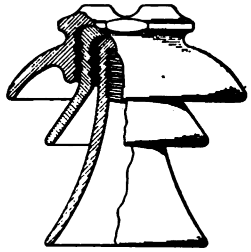


Fig. 41. Petticoat Insulator

Standard Practice. Line wires should have either rubber insulating or weatherproof covering. The weatherproof covering consists of three tight cotton braids, each of which is thoroughly impregnated with some kind of waterproof compound.

The insulation of outside wires on poles is required as an additional protection, but is not in any way depended on for insulation at the supports. The use of bare wires to hold the line wires would greatly increase the probability of crosses in cases of breakage of wires.

Standard practice is to use glass or porcelain insulators at least 1 foot apart on pole cross-arms and to ground all metallic sheaths of cables. Fig. 41 shows a cross-section of one form of porcelain insulator. The "petticoats" will nearly always have a dry space underneath their lower edges, and even if not dry, the length of the path offered to the current escaping over the wet surface is so great that the leakage is small.

All joint wires should be soldered and carefully insulated. The joint should be made mechanically and electrically secure before the solder is applied. Good joints are requisite to lessen the chance of wires falling as well as to prevent arcs on the wires themselves.

Proximity of Wires to Electric Light and Power Lines. Probably the most common and also the most dangerous fault in outside work is the running of telephone and other signal wires too close to electric light and power lines. Wires of this sort should never be on the same cross-arms and it is much the best practice wherever possible to keep telephone wires on poles on one side of a street, and light and power wires on the other, giving special attention to the necessary crossings, if any. In all outside pole work in towns due regard should be given to the fact that lines consisting of many wires are a serious hindrance to firemen in attacking a fire in the adjacent

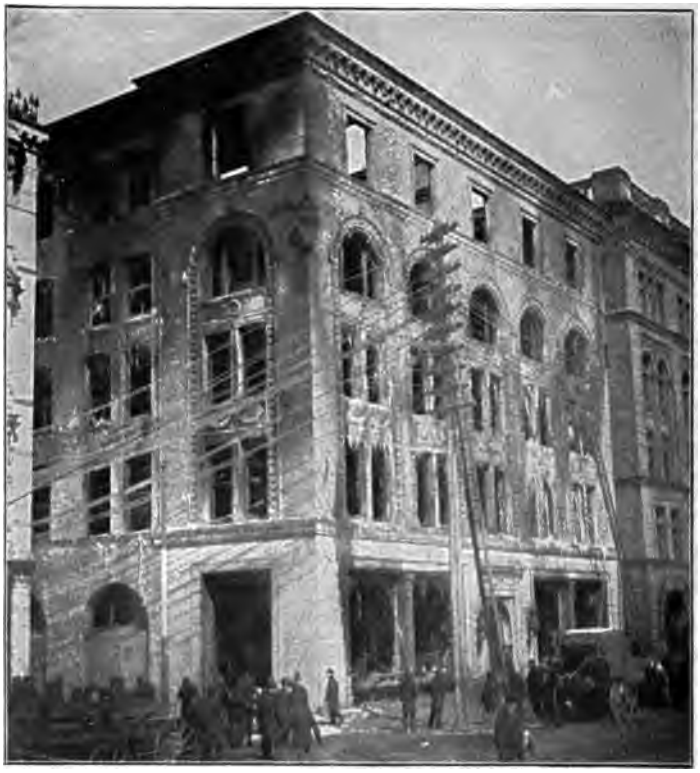


Fig. 42. Presence of Overhead Wires Hinders Firemen

buildings, Fig. 42. The disposition of the lines should be such as to reduce this as far as practicable; but placing wires underground is the only complete solution of this problem.

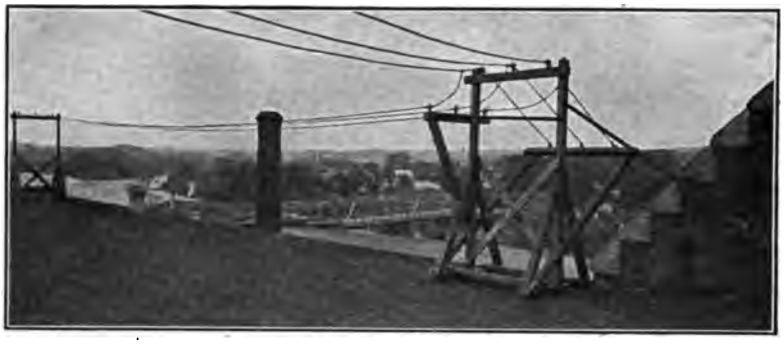


Fig. 43.* Well-Installed Roof Wiring

Outside Wires on Buildings. Where outside lines are supported on buildings, they should be at least 7 feet above the highest point of flat roofs and at least 1 foot above the ridge of pitch roofs over which they pass and the roof structures should be of the most substantial description. Figs. 43 and 44 show two forms of roof structure which hold the wires high enough so that they cannot sag and

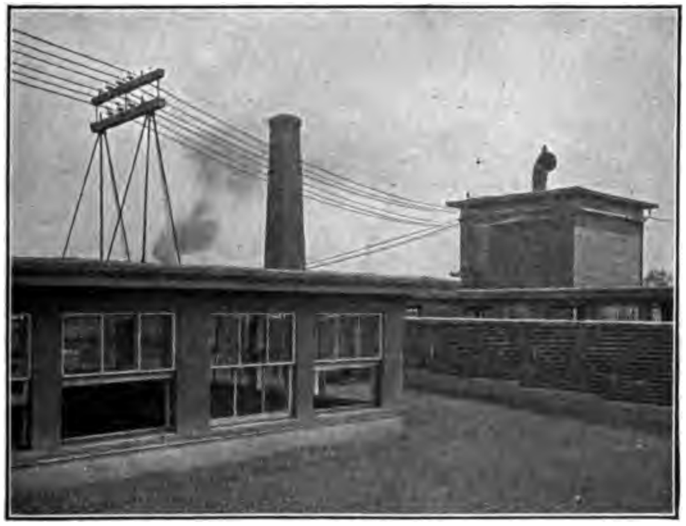


Fig. 44.* Approved Form of Roof Structure for Safe Installation

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Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.

touch the roof and so that they are not liable to be touched or disturbed by persons walking on the roofs. Where outside wires are brought from pole lines into buildings special precaution must be taken. Such wires are spoken of as service wires or services.

The portion of such wires from the service switch in the building and the first outside support must be rubber insulated. Every precaution must be taken to keep service wires free from contact with cornices, awning-frames, shutters and the like, under all conditions.

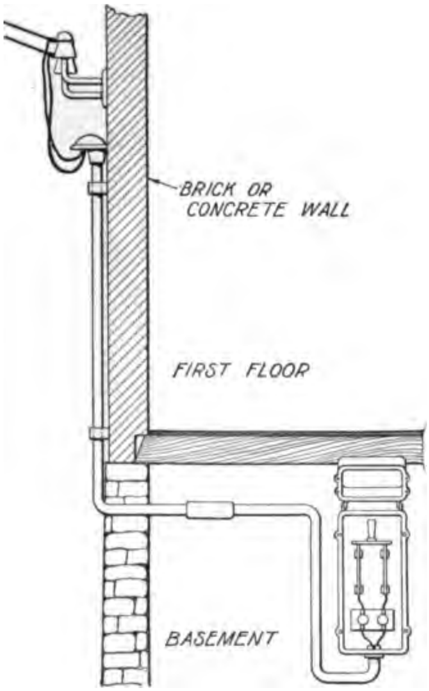
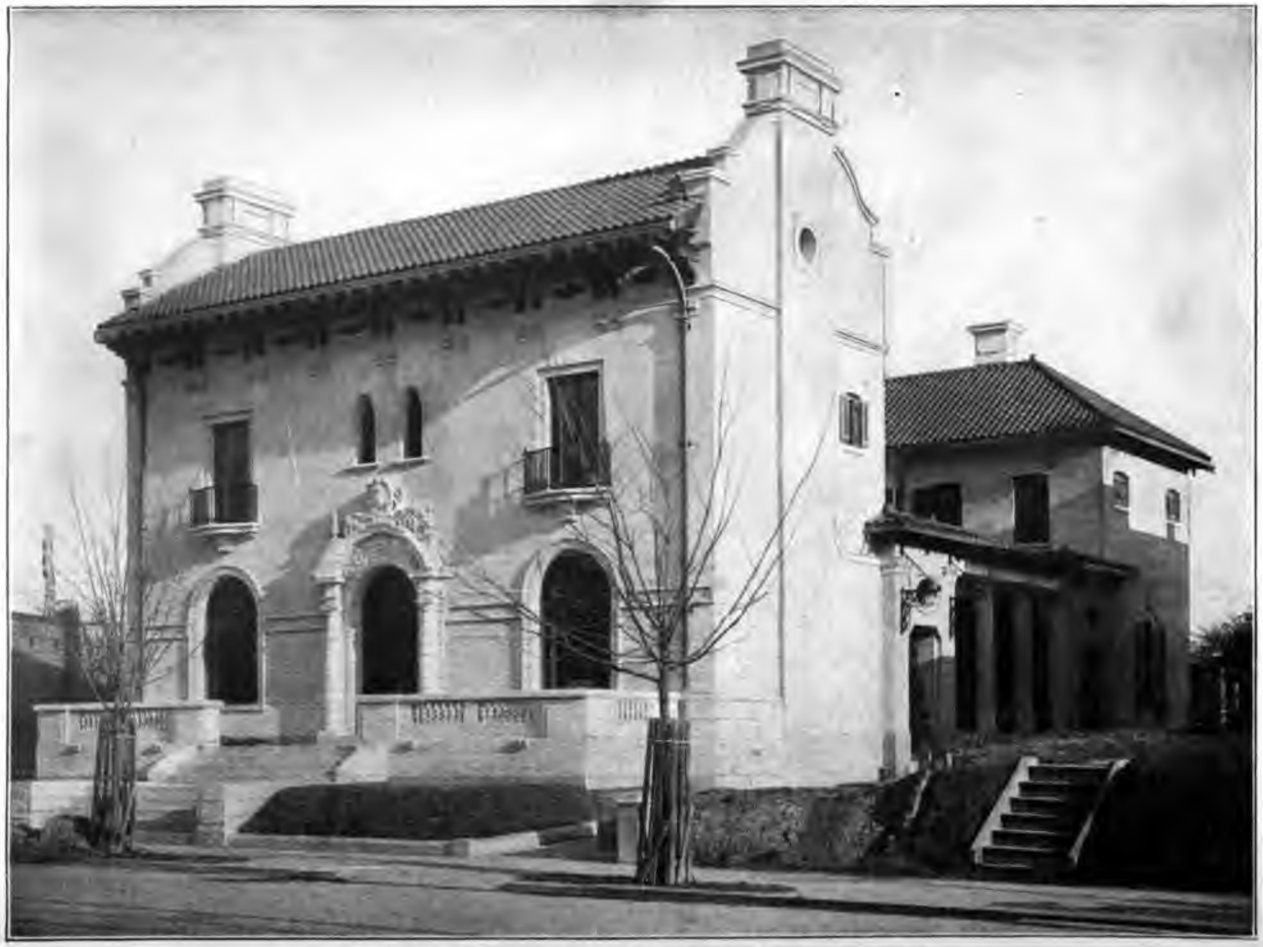


Fig. 45. Section of Approved Conduit Wiring Showing Provision Against Moisture

Usually, for low-voltage circuits, it is best to put the wires in metal conduit, as shown in Fig. 45. This drawing also shows the drip loops which should always be provided, the insulators on brackets secured to the wall and the special *pipe-cap* on the top of the conduit to keep rain out of the pipe. Where conduit is not used, porcelain bushings may be used, slanting upward through the wall toward the inside.

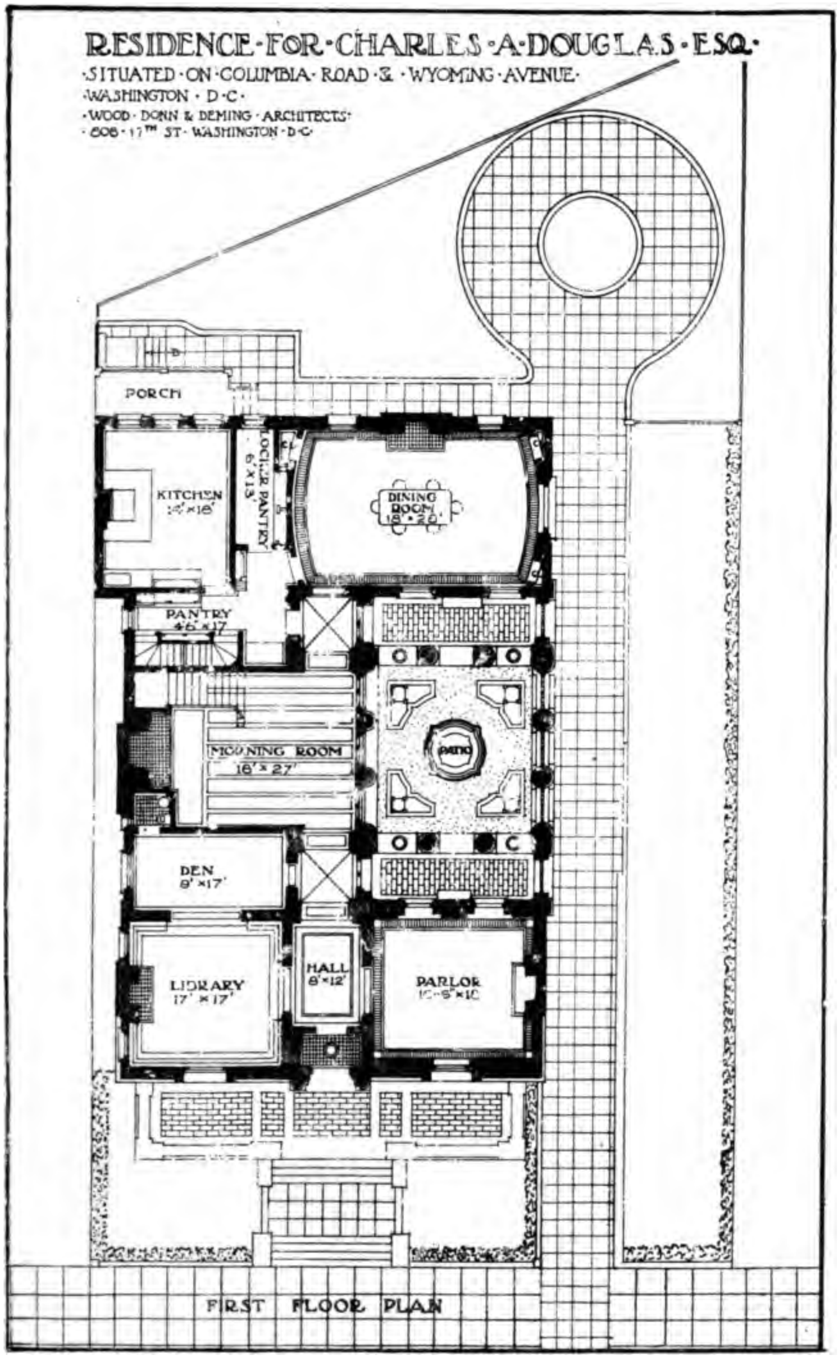
In general it is better to have service wires enter through the basement rather than through an upper story or attic. Where wires are carried along side walls outside of buildings, they should be supported on glass or porcelain insulators, not more than 15 feet apart. Where not exposed to weather, porcelain knobs may be used if not more than 4½ feet apart.

Trolley Wires. Trolley wires must be of ample size for mechanical strength (No. 0 B. & S. gauge copper or No. 4 B. & S. gauge silicon bronze). Protection against crosses must be ample and street railway trolleys and feeder cables must be capable of being disconnected at the power station or of being divided into sections so that in case



HOUSE FOR CHAS. A. DOUGLAS, ESQ., WASHINGTON, D. C.

Wood, Donn & Deming, Architects, Washington, D. C.


RESIDENCE · FOR · CHARLES · A · DOUGLAS · ESQ ·
· SITUATED · ON · COLUMBIA · ROAD · & · WYOMING · AVENUE ·
· WASHINGTON · D · C ·
· WOOD · DONN & DEMING · ARCHITECTS ·
· 808 · 17TH ST · WASHINGTON · D · C ·
PORCH
KITCHEN
14'×18'
LOCKER PANTRY
6'×13'
DINING ROOM
18'×20'
PANTRY
4'6"×17
MORNING ROOM
18'×27'
PATIO
DEN
9'×17'
LIBRARY
17'×17'
HALL
8'×12'
PARLOR
16'-9"×16
FIRST FLOOR PLAN

FIRST-FLOOR PLAN OF HOUSE FOR CHAS. A. DOUGLAS, ESQ., WASHINGTON, D. C.

Principal Rooms Grouped about an Open Court or Patio. Main Living Room, or "Morning Room," Looks Out upon Court through French Windows, which in Summer are Thrown Open, Providing Abundant Light and Air. On Second Floor, over Passageways on Each Side of Court, are Porches upon which Bedrooms Open, Thus Providing Comfort through the Hot Midsummer Nights. The Massing of Flowers and Vines on these Porches at the Parapet Line of the Tile-Covered Eaves, Adds a Most Pleasing Effect. Exterior Shown on Opposite Page.

of fire on the railway route, the current may be cut off from the particular section and not interfere with the work of the firemen.

Electrolysis. Whenever an electric current passes between a pipe or wire underground into damp earth an electro-chemical effect is produced which may, under certain conditions, produce a disintegrating effect on the metal pipe or wire and eventually destroy it. Whenever an electric current passes through a conducting liquid which is not a chemical element, the liquid is decomposed. The salts and acids in the liquid are thus decomposed and metal plates by which the current is led into and out of the liquid are also affected. This process is called *electrolysis*, that is, breaking up of chemical composites by electric currents.

It is at once evident that water and gas pipes of iron buried in moist earth provide the necessary combination for electrolytic effects and that pipes in areas traversed by currents through the earth may be injured by such chemical disintegration. In cities and towns where there are large electric currents which use the earth as a "return path," these effects, if improper conditions are allowed to exist, may become very serious and have a bearing on the fire hazard chiefly as they may jeopardize the water mains and supply pipes to an extent sufficient to render the fire-fighting facilities unreliable in emergencies. Since the direction of alternating currents reverses many times each second, the chemical effects which they can produce are also reversed and, therefore, in general alternating currents in the earth are not liable to produce dangerous electrolysis. There are, however, direct currents which usually employ ground returns and by far the commonest are the currents of the usual overhead trolley street railways. It is to these, therefore, that the following explanation applies. Fig. 46 illustrates the way in which the current in a trolley circuit returns to the generator. Such circuits in this country

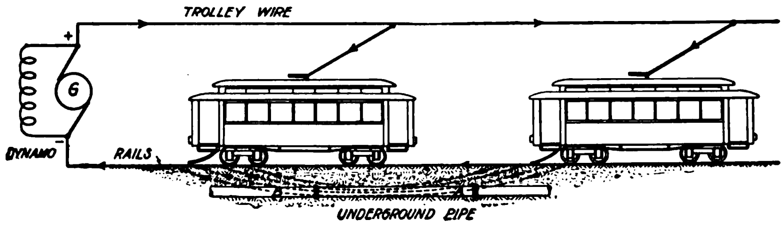


Fig. 46. Diagram of Electrolytic Effects of Street Railway Return Currents

are almost invariably direct current at 500 to 650 volts and the *positive* side of the dynamo is regularly connected to the overhead wire. The current thus passes out over the trolley, through such cars as are in operation and back to the negative side of the dynamo, by the rails, or through pipes, moist earth or other conducting substances underground. The negative side of the generator is, of course, connected to the rails and ground. The return current divides according to the conductivity of the different paths afforded it and the actual distribution of currents in the earth may be very complicated and is subject to great variations from point to point. Careful "electrolytic surveys" are necessary in order to discover fully the actual current arrangements existing underground in any town or city.

In general, however, it is important to notice that wherever the current *leaves* a pipe for the earth, as at *B* in Fig. 46, the iron of the pipe is carried away into the earth, just as in a silver plating battery, silver is carried away from the silver plate toward the article which is being plated. It is this action which is meant by electrolysis as the term is usually employed with reference to underground pipes and earth currents and the result, as has been stated, may be a destruction of the pipe at one or at many points.

For the diminution of such electrolytic corrosion every means should be taken to afford a low-resistance path for the return circuit. This is also of advantage from the viewpoint of economical operation since it takes power to drive the current through a high-resistance return path. Large copper conductors are often laid between the rails and parallel to them, frequent heavy cross wires being used to connect this copper cable to the rails. Good bonds between rails either of low-resistance tie plates, or still better of electric welds between rail ends, are of great value.

The general arrangement and size of return wires and rail should be such that the difference of potential in volts between the grounded terminal of the generator and any point on the return circuit will not be more than 25 volts.

Where pipes or other underground metal work are found to be electrically positive to the rails or surrounding earth, that is, so that current tends to flow *from the pipes to the rails or earth*, special conductors should be provided to connect the pipes to the rails to carry such currents and thus prevent, as far as possible, the effects of electrolysis. Very elaborate investigations of electrolysis as affecting water mains, gas pipes and other underground metal have been made in many cities and the co-operation of city authorities, water companies, and electric power and railway companies, has in many places resulted in greatly lessening, if not in entirely removing, the dangers from this cause. Surveys should be repeated occasionally since new electric circuits or new pipe lines may create an altered condition in underground distribution of currents.

High Tension Lines. In recent years there has, in most parts of the country, been a very great increase in the number of high-tension power-transmission lines and the voltages have also become much higher. Overhead lines of this class present certain problems requiring very careful attention. The Code states the following causes of fire which may come from high-voltage (over 5,000) lines:

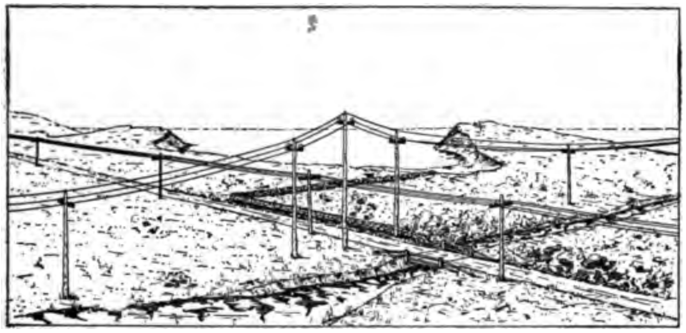


Fig. 47.* Crossover Arrangement for High-Tension Circuits

> Accidental crosses between such lines and low-potential lines may allow the high-voltage current to enter buildings over a large section of adjoining country. Moreover, such high-voltage lines, if carried close to buildings, hamper the work of firemen in case of fire in the building. The object of the rules is so to direct this class of construction that no increase in fire hazard will result, while at the same time care has been taken to avoid restrictions which would unreasonably impede progress in electrical development.
>
> It is fully understood that it is impossible to frame rules which will cover all conceivable cases that may arise in construction work of such an extended and varied nature, and it is advised that the Inspection Department having jurisdiction be freely consulted as to any modification of the rules in particular cases.

** Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.*

The very best way to guard against accidental crosses between high-tension lines and other circuits is to have them follow different routes. This can often be accomplished by mutual agreement of the parties interested even when a change in one of the routes will be necessitated.

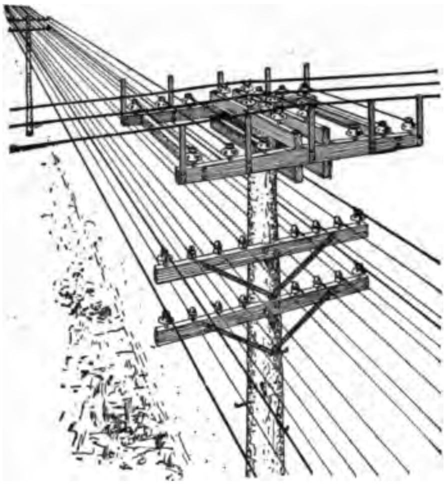


Fig. 48.* Joint-Pole Crossing with Mechanical Guards

High-tension lines should not approach other pole lines nearer than a distance equal to the height of the taller pole and such lines should not be on the same poles with any other lines except such signal lines as may be used by the company operating the high-tension system.

Where such lines must necessarily be carried nearer to other pole lines than is specified above, or where they must necessarily be carried on the same poles with other wires, extra precautions to reduce the liability of a breakdown to a minimum must be taken, such as the use of wires of ample mechanical strength, widely spaced cross-arms, short spans, double or extra heavy cross-arms, extra heavy pins, insulators, and poles thoroughly supported. If carried on the same poles with other wires, the high-pressure wires should be carried at least 3 feet above the other wires, but this arrangement should never be adopted unless it is impossible to do otherwise. Where such lines *cross* other lines, the poles of both lines must be of heavy and substantial construction.

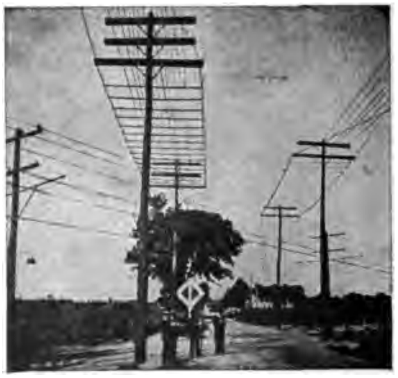


Fig. 49.* Use of Screen on High-Tension Crossover

The Code contains quite detailed specifications for the safe construction of crossovers and other details of high voltage lines which should be carefully studied and followed.

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* *Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.*

Fig. 47 shows one arrangement for a crossover. A *joint-pole crossing* may sometimes be used and Fig. 48 shows such a crossing with mechanical guards and wires on the upper or high-tension line cross-arms. Sometimes a screen either supported on high-tension insulators or grounded may be suspended between the lines at the crossover as illustrated in Fig. 49. When necessary to carry high-tension lines near buildings they should be at such height and distance from the building as not to interfere with firemen in event of a fire. Such interference might arise either from the difficulty of placing ladders or from the danger of shocks to firemen holding hose nozzles, streams from which might strike the high-tension lines.

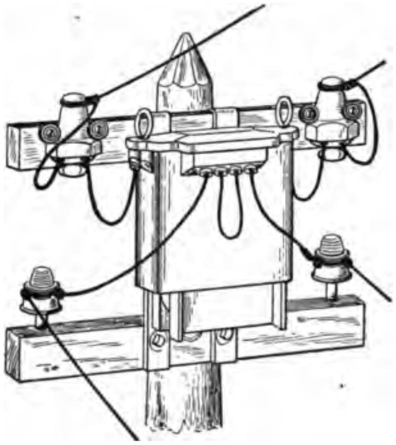

Fig. 50. Approved Pole Installation of Transformer

Mounting of Transformers. Oil-cooled transformers should not, in general, be installed in buildings, and an outside location is always preferable; *first,* because it keeps the high-voltage primary wires entirely out of the building; and *second,* because of the possible injury from smoke and oil in case the transformer burns out or is overloaded. Figs. 50, 51, and 52 show transformers installed on a pole, on the outside wall of a mill and in a special fire-proof vault, respectively.

Grounding of Circuits. One of two courses should always be followed with regard to any electrical connection between circuits or apparatus and the earth; either arrange to have no such connection at all, and secure good insulation between live parts of circuits and the earth, or provide a good earth connection of sufficient capacity well installed to care for any current liable to pass to earth, either regularly or in case of accident.

In general it should be remembered, that if an entire electric circuit including the generator, lines, and all connected apparatus

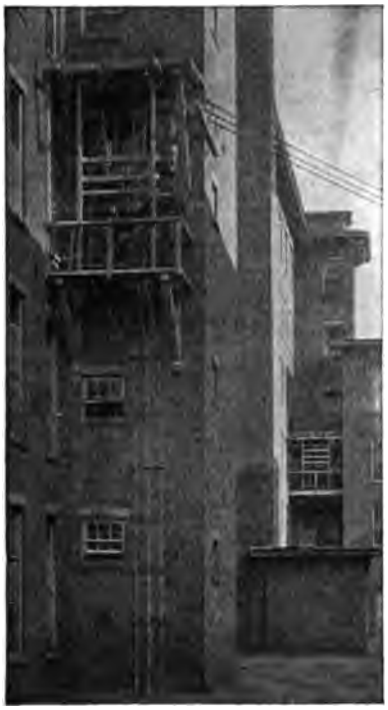

Fig. 51.* Approved Transformer Installation on Outside of Building

and devices are thoroughly well insulated from the ground, *one* accidental ground will produce no effect since there is no return path from the ground to another point on the system. However, we cannot be sure that an installation will be kept free from grounds even if originally so installed, since wear, deterioration of insulating materials, breaking of parts of devices, or the effects of dirt and damp may bring on a "ground" which will not be discovered until a second ground connection is established which permits current to flow with consequent heating and arcing. Under such conditions, the fault is liable to become rapidly worse. Not the least important thing about such failures of electrical circuits, is the danger of injury to persons who may become a part of the ground circuit. Thus a mechanic working on a line shaft in a mill, by touching simultaneously a live part of the circuit or a poorly insulated live wire and the shafting, may make his body part of a path for the current to ground. While 110 volts or 220 volts either a. c. or d. c. are rarely enough to kill a person, painful accidents may be caused directly or indirectly by shock, and voltages of 440, 500, or higher may readily be the cause of death if the conditions are such as to permit any but very small currents to pass through the body. While, of course, liability of injury to persons is not a "fire hazard," still good construction should provide (both in original installation and in upkeep) all reasonable protection, to persons and property.

In direct-current three-wire systems of electrical distribution, the middle or neutral wire is regularly grounded at the central station. In systems where the cables are underground, the neutral must also be grounded at each distributing box, through the box; and in overhead systems the neutral should be grounded every 500 feet. The neutral in such systems is supposed, normally, to carry either no current, or such small amount of current as may result from a different amount of power being temporarily taken from the two outside wires. If in any system the neutral is grounded at all, it should be done thoroughly so as to prevent the current escaping to ground where the connections may be so poor as to cause unsafe heating.

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* *Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.*

Two-wire direct-current systems are not to be grounded at all. Suppose in Fig. 53 some current-carrying part of the dynamo *D* is grounded, that is, in electrical connection with the earth, as through the bolt and the damp wood base of the machine. If this be all, no current will flow so long as there is no other ground connection to any other part of the circuit. But suppose that somewhere in the building a wire touches a gas pipe as at *B* and the insulation on the wire at *B* is worn by vibration or is defective for any reason. The gas pipe is, of course, connected to the earth and the current then has a path through the pipe, earth, bolt, base, and frame of the machine. The whole voltage of the dynamo may, therefore, drive current through this path, causing an arc to form at *B* between the wire and the pipe which will burn a hole in the pipe and set fire to the escaping gas. Evidently the greatest pains should be taken to prevent wires from coming in contact with grounded piping or other metal.

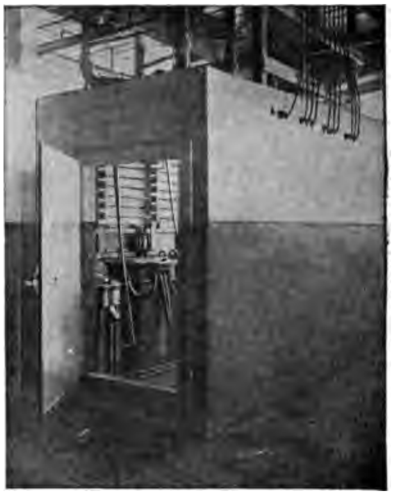

Fig. 52.* Transformer Installation in Fireproof Vault

Alternating-current systems almost invariably include transformers in which the higher line voltage is "stepped down" to the voltage required for lamps and motors. Common line voltages are 1,100, 2,200, and 3,300 volts, while the secondary voltages may be 100, 110, 220, 440 or 550. With such systems as are commonly used for distributing light and power, it is now required that the secondary or low-voltage side be grounded, provided the maximum difference of potential between the grounded point and any other point in the circuit does not exceed 150 volts and they *may* be grounded when this maximum difference of potential exceeds 150 volts. The ground connection may be made either at the transformers or at individual service entrances. At transformers the connection is made at the neutral or middle point of the secondary winding or coil. With three-wire a. c. distributing systems, the neutral wire itself is grounded. Sometimes, when a neutral point is not accessible, *one side* of the secondary circuit may be grounded.

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*Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.

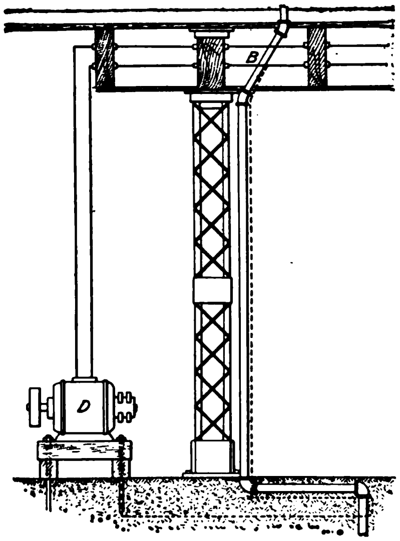

Fig. 53. Faulty Installation of Two-Wire Direct-Current Dynamo

It should be remembered that a poorly made earth connection may be worse than none. The rules, therefore, prescribe in detail how to secure *good* connections. The wire should be of large size and should be run in as nearly a straight line as possible, avoiding kinks, coils, and sharp bends which are objectionable since they impede the flow of alternating-current or lightning discharge.

Individual transformers and building services may be grounded to water pipes by carrying the ground wire into the basement and connecting it to the *street* side of meters, main cocks, etc., so that any resistance which these might offer in the ground path might be avoided.

The underwriters' rules give the following directions for making ground connections:

> In connecting a ground wire to a piping system, the wire should be sweat into a lug attached to an approved clamp, and the clamp firmly bolted to the water pipe after all rust and scale have been removed; or be soldered into a brass plug and the plug forcibly screwed into a pipe-fitting, or where the pipes are cast iron, into a hole tapped into the pipe itself. For large stations, where connecting to underground pipes with bell and spigot joints, it is well to connect to several lengths, as the pipe joints may be of rather high resistance.

Where ground plates are used a No. 16 Stubbs' gauge copper plate, about 3 × 6 feet in size, with about 2 feet of crushed coke or charcoal, of pea size, both under and over it, would make a ground of sufficient capacity for a moderate-sized station, and would probably answer for the ordinary substation or bank of transformers. For a large central station, a plate with considerably more area might be necessary, depending upon the other underground connections available. The ground wire should be riveted to the plate in a number of places, and soldered for its whole length. Perhaps even better than a copper plate is a cast-iron plate with projecting forks, the idea of the fork being to distribute the connection to the ground over a fairly broad area, and to give a large surface contact. The ground wire can probably best be connected to such a cast-iron plate by soldering it into brass plugs screwed into holes tapped in the plate. In all cases, the joint between the plate and the ground wire should be pianted with waterproof paint or some equivalent.

In the past few years, there has been much discussion of this question of grounding, but the general tendency is no doubt more and more in favor of grounding all circuits where so doing will protect life and will not introduce extremely hazardous conditions as regards fire. Companies and departments in charge of water works are urged to allow the attaching of ground wires to their piping systems in the full confidence that the integrity of such piping systems will not in any way be affected whatever may be the normal voltage. The following statement is taken from the explanatory notes of the Associated Factory Mutual Fire Insurance Companies:

If the primary and secondary coils of a transformer come into contact electrically, the high-voltage primary current may flow to the secondary system. If this should happen, the life of any one handling any part of the secondary system would be endangered, and fires would probably be started by arcs caused by breaking down of the insulation of the wires or fittings on the secondary system. If, however, the secondary coil is grounded, a breakdown in the transformer cannot cause a dangerous difference of potential between the secondary system and the ground, and only with certain unusual combinations of contacts between the primary and secondary wires outside of the transformers will this protection fail to prevent the voltage of the secondary system from being raised above its normal limit. To secure the full benefit of the ground connection, reliable primary fuses must be provided.

The *middle* of the secondary coil is the proper point to ground, as there is then only half the normal secondary voltage between either side and the ground, thus reducing the liability of a breakdown of insulation and also materially lessening the danger of fire if a breakdown does occur.

There is an objection to grounding the secondary on the other hand, for when this is done, the first breakdown of insulation may mean a short-circuit and a possible fire. With a system free from grounds, a breakdown must exist on each side of the system to cause a short circuit: with proper detectors the first can generally be found and remedied before the second occurs.

Grounding is, therefore, a choice of evils, but in many cases it is believed to be a lesser one than to risk getting the primary current on the secondary system. This is especially true where the primary voltage is high, say 3,500 or over. For this reason it is advised that all transformers be so designed and connected that the middle point of the secondary coil can be reached if, at any future time, it should be desired to ground it.

After the transformer secondary has been properly grounded a test should be made, especially if the transformer is some distance from the building supplied, in order to determine if the protection expected from the ground connection at the transformer is really effective inside the building in question, and if not the connection should be extended to accomplish the desired result. Cases have been known where the effectiveness of a ground connection has been limited to a comparatively small area, due to the exact conditions of the earth in the neighborhood of the ground plate and between it and the point where the protection due to the grounding was desired. The entire ground connection should be carefully examined at least once a year.

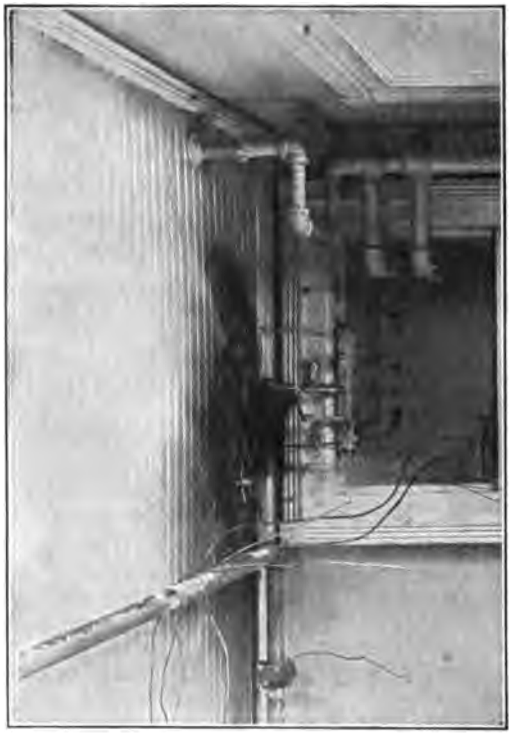

Fig. 54. Effect of Short-Circuit from Lighting Wires to Bell Circuit

INSIDE WORK

Under this heading are included the rules for wiring and appliances for light, heat, and power distribution and use. These cover the most general cases of electrical installations as they relate to fire prevention and protection in buildings of all classes. The installation of wires and apparatus for signaling systems, such as electric bells (battery current bells), telegraphs, telephones, fire alarms, and the like, is not covered in the general rules for "Inside Work" since they usually present no hazard in themselves but only as they may become dangerous because of their liability to become crossed with light, heat, or power wires either outside or inside of buildings, Fig. 54.

WIRING SYSTEMS

The present approved methods of electrical work inside buildings in this country have been developed through many years of experience, beginning with the first applications of electricity for lighting buildings and gradually changing as the possible dangers became more generally recognized, and as improved means of guarding against them were devised. In this development the efforts of insurance and municipal authorities have been supplemented by an immense activity on the part of inventors and manufacturers in supplying new devices and materials. The net result has been on the one hand an elaboration of rules and an approach to a few standard systems of construction and on the other hand the production of an almost endless variety of materials available for electrical purposes. Methods and materials which at first seemed adequate have become obsolete after a few years' use. At present, however, few important changes appear to be in progress but in many minor details the development is still going on.

At first, electric wires were laid as seemed most convenient in floors, partitions, and over walls and ceilings, either in channels cut for them, in wood casings, or supported on wood cleats with almost no regard to protecting the wires from injury, or the adjacent combustible materials from being ignited by overheated wires or by arcs. Today, however, these earlier crude methods are wholly abandoned and it is generally conceded that the best protection against electrical fires lies in the adoption of the most approved methods even when the first cost of an installation is increased to some extent. Fig. 55 shows some defective wire joints as found in actual use.

In buildings of the better class, the electric installation is carefully considered in the plans, and provision is made for its safety as well as for its efficiency and economy. However, in cheaper buildings, and very often in small stores, apartments, and residences, the electrical work is left to be arranged as best it may and to be installed by careless workmen without expert supervision. In electrical matters as in most other affairs, cheap work is generally poor work, and deviation from the methods shown by experience to be reliable are usually prompted by a desire to save money at the expense of safety and permanence.

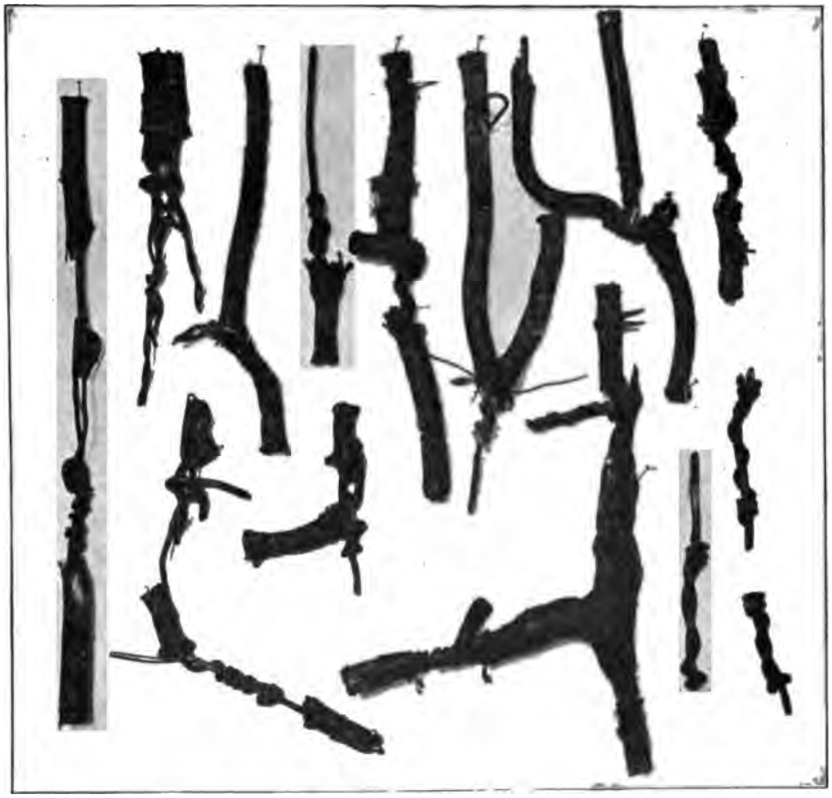

Fig. 55. Typical Defective Joints in Electric Installation

The method of bringing supply or "service" wires into buildings naturally demands first attention. Where street mains are underground the lines should, wherever possible, enter through the basement or cellar walls, the lead-covered cables being carried through the foundations through tubes tightly sealed.

Where mains are overhead, the supply wires may enter either through the basement, being carried down the outside of the wall in iron conduit, or through some upper portion of the wall, though the former entrance is almost always preferable. Where transformers are used they may be on poles near the building or mounted on the outside wall in a substantial manner. An entrance through a roof, near a cornice or into little used or inaccessible attics or lofts, should be avoided. Where wires or cables pass through the outside walls there must be either iron conduit or insulating bushings sloping upward toward the inside, and the wires outside must have drip loops which will prevent moisture following along them into the wall. The fastenings of the wires to the building must be most substantial and good insulators must be provided for the supply wires. Fig. 56 shows the method where bushings are employed. If the entrance is made through conduit, the inner end of the conduit should always be extended to the service fuses. At the nearest accessible place in the building must be placed what are called the service fuses and the service switch. The switch is usually of the knife-blade pattern and must be such as to cut off all the wires. Single-pole switches must never be used as service switches. The purpose of service switches is to provide means for cutting off current for repairs or in case of fire or other accident. The service fuses should be placed between the service switch and the mains to the outside of the building. Their purpose is to protect all the wires inside the building from overloads, and they should be such as to melt or "blow" with current not much in excess of the normal full current likely to be taken by the entire installation which the service supplies.

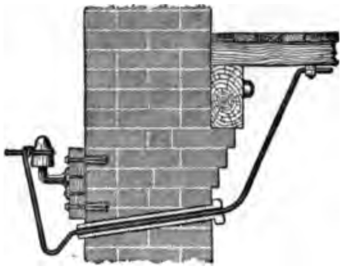

Fig. 56.* Method of Using Bushings

Service switches and fuses take many forms, from a pair of small "plug fuses" and knife switch on a porcelain base to quite elaborate switchboards which carry both these and other sub-fuses for the main circuits within the building. The same principle, how-

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Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.

ever, applies to all; all wires must be protected, the service entrance must be accessible and fuses must be of proper capacity. From the service switch the lines usually extend through meters to distribution centers which are panels from which the several sub-circuits branch off to lamps or motors through the building. Fig. 57 shows such a center. There may be only one such center in a small installation, or in a larger one there may be a main distributing panel and numerous smaller ones at various places in the risk.

General Rules on Wires. *Size.* No wire smaller than No. 14 B. & S. gauge is allowed (except in fixtures and for pendant or flexible cord) since no smaller size has both the conductivity and also sufficient mechanical strength to stand the strains of installation and use.

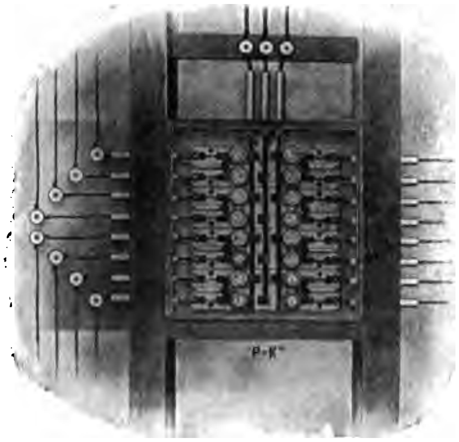

Fig. 57. Distributing Panel for Lighting Circuit

Joints and Splices. All joints and splices must be made both mechanically and electrically secure *and then be soldered* except when one of the very few approved splicing devices is used. For general wiring, the underwriters have never found any equivalent for *good* soldered joints when all the possible effects of corrosion, alternate heating and cooling, vibration, and mechanical strains are considered. The neatness and thoroughness of the soldered joints are two of the best general indications of the excellence of the workmanship on any job. After being soldered wire joints must be covered with an insulation equal to that at other places on the conductors. This is usually done by winding the joints with a good pure rubber tape over which is wound a "friction tape" of fabric impregnated with a compound.

Wires in Walls, Floors, etc. Wires must always be separated from walls, floors, timbers, and partitions by non-combustible, non-absorptive, insulating tubes such as glass or porcelain and must be kept free from all contacts with pipes or any conducting material. This general rule is established without any reference to the insulation which is on the wires themselves, the idea being that the insulation of the conductors from each other and from other conducting materials must be sufficient to furnish the necessary protection in case the wire coverings are defective or become injured in any way. This principle does not, however, prevent the wires being drawn into metal conduits which are specially designed as wire raceways, nor can it apply to fixtures in which the wires must be in the metal stems and arms. For such cases special rules are established. Fig. 58 shows a good example of overhead wiring in which an iron pipe may be seen protecting wires up the post, while the wires on ceiling and around beams are very well arranged and supported.

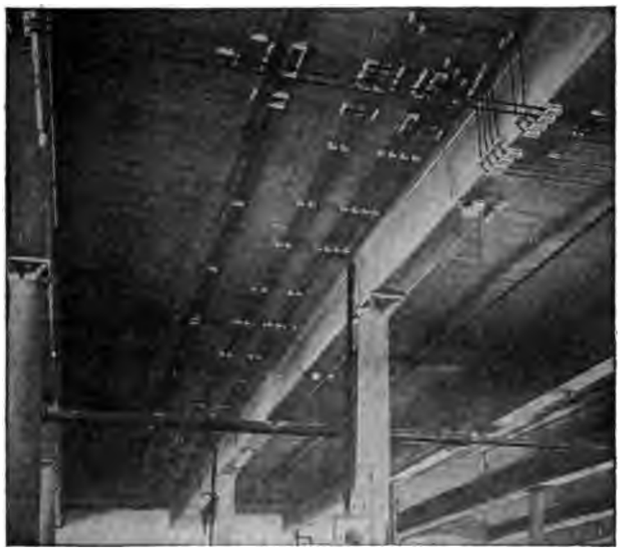

Fig. 58.* Approved Overhead Wiring

In damp or wet places, the relative arrangement of pipes and wires should be such that the wires cannot touch the pipes and so that water cannot drop from the pipes on the wires. The subject of electrical work in damp places will be considered in another place.

Carrying Capacity. The Code prescribes the maximum current which shall be carried on copper wires of different sizes. This table, which has been recently somewhat revised, was originally based upon an elaborate series of careful experiments. Table III gives the revised figures for rubber-covered wires, and for all types of wire insulation such as slow-burning and weatherproof braids.

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* *Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.*

The table for rubber-covered wires is lower than the other because high temperatures such as might result from a wire carrying too much current have a harmful effect on the insulating properties of rubber. The table is for indoor work only. It is stated that for any given size of wire, a current about three times as great as that given in Table III will cause all ordinary insulations to smoke. The table does not consider the question of *drop* as it is called. Thus in Fig. 59, suppose D is a dynamo supplying current to M, a motor 250 feet away from it, and suppose the motor requires 90 amperes at 220 volts. From Table III it is seen that No. 2 wire could be used. But some *power* is lost in driving the current through the 500 feet of line wire and, if the wire is small, its resistance will be large and so more power will be "lost on the line wires." The part of the dynamo voltage required to drive the working current over the supply wires is called the "drop." Suppose it is prescribed that the drop shall not be over 1 per cent of the total voltage. One per cent of 220 volts is 2.2 volts. The current in the line equals the voltage to force the current over the line divided by the ohms resistance of the line. In this case $90 = \frac{2.2}{\text{resistance}}$, or resistance of the 500 feet of wire must not be more than $\frac{2.2}{90}$ ohms or .024 ohms. From a suitable wire table it will be found that a No. 0000 wire will be required. Thus the necessity of keeping the loss of power low on the line may necessitate the use of a larger wire than would be needed for safety under the underwriters' rules.

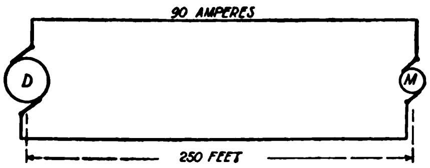
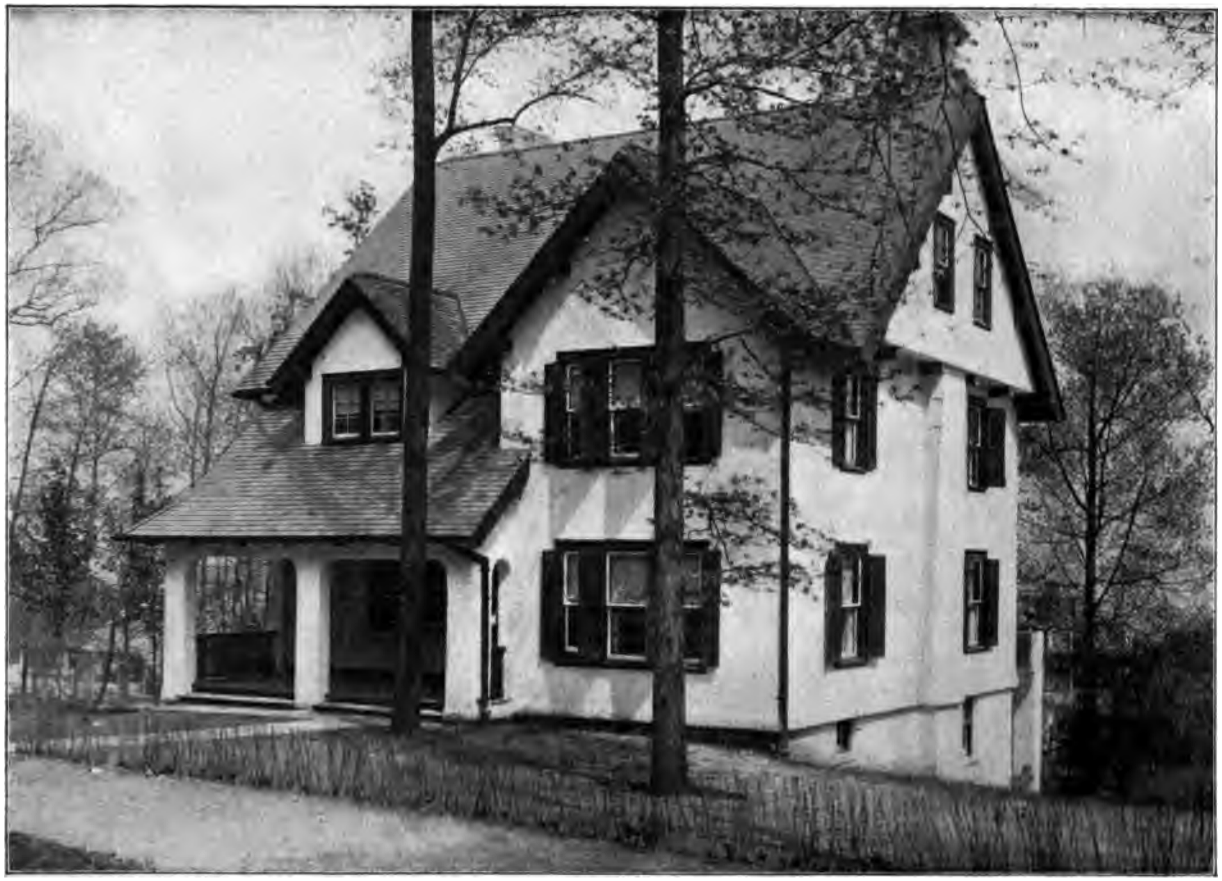
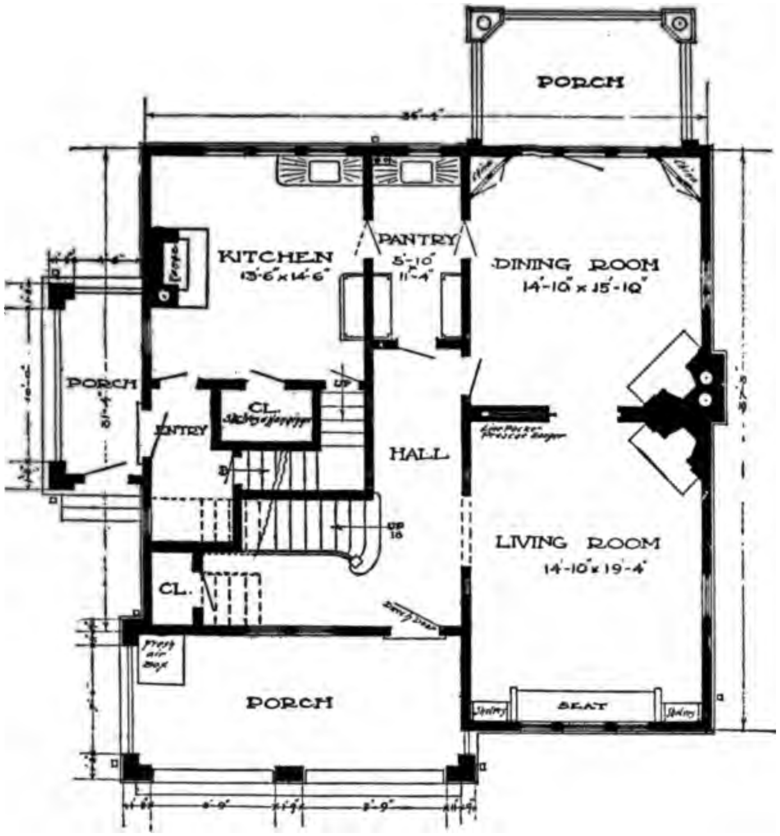


Fig. 59. Simple Electric Power Circuit

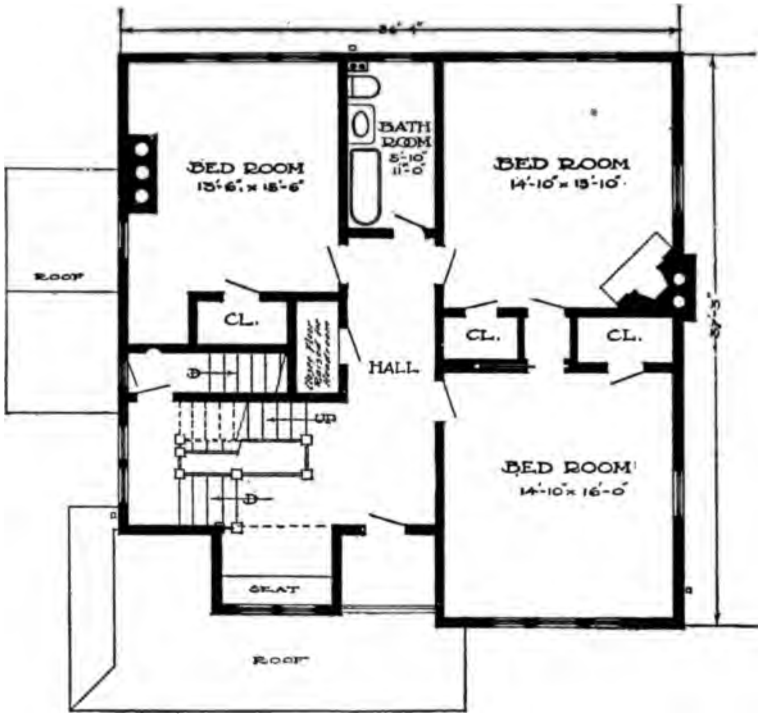
Constant-Current Systems. The nature of these has already been explained on page 13. Such systems are used nowadays almost exclusively for street lighting with arc lamps and the voltage runs



RESIDENCE OF C. D. DU BOIS, MONTCLAIR, NEW JERSEY
N. Le Brun & Sons, Architects, New York.
Walls of Stucco on Herringbone Expanded Steel Lath. For Plans, See Opposite Page.



FIRST FLOOR PLAN



SECOND FLOOR PLAN

RESIDENCE OF C. D. DU BOIS, MONTCLAIR, NEW JERSEY
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TABLE III

Carrying Capacity of Wires

B. & S. G.	Rubber Insulation Amperes	Other Insulations Amperes	Circular Mils
18	3	5	1,624
16	6	10	2,583
14	15	20	4,107
12	20	25	6,530
10	25	30	10,380
8	35	50	16,510
6	50	70	26,250
5	55	80	33,100
4	70	90	41,740
3	80	100	52,630
2	90	125	66,370
1	100	150	83,690
0	125	200	105,500
00	150	225	133,100
000	175	275	167,800
0000	225	325	211,600
Circular Mils			
200,000	200	300	
300,000	275	400	
400,000	325	500	
500,000	400	600	
600,000	450	680	
700,000	500	760	
800,000	550	840	
900,000	600	920	
1,000,000	650	1,000	
1,100,000	690	1,080	
1,200,000	730	1,150	
1,300,000	770	1,220	
1,400,000	810	1,290	
1,500,000	850	1,360	
1,600,000	890	1,430	
1,700,000	930	1,490	
1,800,000	970	1,550	
1,900,000	1,010	1,610	
2,000,000	1,050	1,670	

from 2,000 to 3,300 volts. The arc lamps on such circuits are arranged so that each line has enough lamps in series to use the available dynamo or transformer voltage allowing the necessary margin for regulation.

The high voltages generally employed, call for the very best insulation and only rubber-covered wire should be used; all wires in buildings must be in plain sight and never encased. The bringing of such circuits into buildings is not very general and arc lamps designed to be connected in multiple on ordinary low-voltage circuits are much to be preferred.

There are special rules for series arc-lamp wiring in buildings which cover the method of bringing supply wires through the walls, provision for a special form of switch at points where the lines enter and leave the building, requirement for 1 inch separation between wires and the surfaces over which they pass and 8 inches from each other and extra protection of all wires by running boards or guard strips. The service switch required on constant-current systems must be a *double-contact* switch, that is, it must be so arranged as to first place a cross connection or short-circuit on the lines into the building and then disconnect these lines from the supply altogether. This leaves the circuit unbroken, but cut out of the building. An attempt to actually break the circuit would be sure to cause a very destructive arc. Series arc lamps must be carefully isolated from all inflammable stuff and unless they are of the "enclosed arc" type must be provided with screens and nets to prevent the escape of sparks from the carbon or melted copper. All connections must be made in a most reliable manner and in all series arc work it must be remembered that the voltage across any break in the circuit is very high and will cause very severe arcing.

Incandescent lamps are not generally connected to series circuits since their use involves an automatic cut-out at each lamp which will shunt the current around the lamp in case the lamp becomes loose or its filament breaks. These devices are expensive, difficult to keep in order and generally undesirable. Formerly, combinations of incandescent lamps on series circuits were used, consisting of groups of lamps in series or in multiple, but these arrangements are not now in use and are forbidden in the rules. It is evident that incandescent lamps on series circuits should never be allowed on gas fixtures since an arc to the grounded gas pipe would be very severe and would be liable to burn through the pipe and ignite the escaping gas.

Constant-Potential Systems. The character of these systems has been explained on page 12. Almost all systems for light and power in buildings of all sorts are of this type. The most common are 110-volt two-wire direct-current systems; three-wire systems with 220 volts between outside wires and 110 volts between the neutral and either outer wire; 500- to 600-volt d. c. street and elevated railroad systems with "ground return"; 440- to 600-volt a.c. systems for motors. In addition there are 1,100-, 2,200-, and 3,300-volt a. c. power circuits and the so-called a. c. transmission lines at all voltages from 1,000 up to 80,000 or 100,000 volts. While occasionally a. c. motors are made for direct operation at 1,100 or 2,200 volts, in general for voltages above 600 volts, alternating-current transmission lines are employed which are connected to transformers at the factories or mills where the power is used and which "step-down" the voltage to 440 volts or some other voltage which can conveniently be used in the motors and for lighting purposes. Both the primary and secondary circuits in this case are constant potential systems.

In street railway work large machines called rotary converters are employed which are driven by the high-voltage alternating current from transformers connected to the transmission lines and which deliver direct current at about 600 volts to the trolley system. Such rotary converters are usually placed in substations so located as to conveniently and economically supply the different sections of a city. A similar practice is followed in cities where direct current is to be furnished for general lighting and power, and the original generating station is more or less remote. Such substations come under the same rules as generating or dynamo stations.

All so-called isolated plants, that is, plants in individual factories or large buildings, are constant-potential systems also. In the underwriters' rules constant-potential systems are subdivided into *low potential systems* up to 550 volts; *high-potential systems* 550 to 3,500 volts; and *extra-high-potential systems* over 3,500 volts. Of these the low-potential systems are of most importance since they include the very great majority of equipments for using electricity in buildings for light, heat, and power.

GENERAL INSTALLATION RULES FOR CONTROLLING AND PROTECTING DEVICES

Switches, fuses, and circuit breakers may all be described as arcing devices, that is, their operation always produces an arc. This arc may be small or large but it is impossible to break a circuit-carrying current without some arc even if it is so small that it is a mere spark. The duration and intensity of an arc depends upon the strength and voltage of the current, the rapidity with which the gap in the circuit is widened, and the design and condition of the arcing device, switch or fuse. Dust or inflammable gases may be ignited by an arc of sufficient intensity. No arcing device, therefore, should be placed near easily ignitible stuff, or exposed to inflammable gases, or dust, or flyings of any combustible material. When so exposed, as in flour mills, textile mills, etc., all switches and fuses should be enclosed in dust-tight boxes or cabinets. Open-link fuses are especially liable to flash violently and throw out molten metal and they must, therefore, be given special attention, and should never be installed outside of proper cabinets except on switchboards in fireproof rooms, such as engine rooms, generating stations, or where they will be under constant and expert supervision. Even in ordinary rooms, houses, stores, or factories, where there is no dust or combustible flyings in the air, it is much better to have all knife switches and all fuses placed in cabinets to prevent accidental short-circuits, caused by laying a metal object across the exposed parts.

Switches immersed in oil are in common use for large currents and are quite safe as regards arcing, though the oil involves a certain hazard since it is combustible.

It should be remembered that any switch or circuit breaker which is automatic, that is, which is not operated by hand by a person at the actual device itself, requires better protection since in case of failure the arcing may be severe and no one may be at hand to take the needful steps to prevent its starting a fire. Such automatic current-breaking devices including time-switches worked by clocks, sign flashers, and the like, should always be enclosed in very substantial non-combustible cases or cabinets of ample size and so arranged that they are not liable to be left open.

Switches. The general requirements for service switches have already been discussed. While it is true that the service switch and a switch for every motor are the only ones that are absolutely required by the rules, still convenience and economy of operation naturally call for a number of switches in practically every installation, and the correct placing of them becomes, therefore, a matter of importance. The description of some of the very numerous types of switches will be given later in this book, but we consider here the general rules for installing all types.

As a general principle, switches must always be placed in dry, accessible places and it is well to group them together so far as possible for the reason that this will often reduce the amount of wiring and also render it easier to use them in case of need.

Knife Switches. Knife switches consist of copper blades, one for each pole, hinged at one end to copper clips or posts and closing at the other into other clips. Where such a switch is made to close into clips at only one side of the hinge end it is called a *single-throw* switch and where the blades can be thrown into clips at either side of the hinge it is called a *double-throw* switch. Single-throw switches must always be installed so that gravity will tend to open rather than close them since otherwise they might fall and, by only partly closing, cause arcs and burning. Double-throw switches may be installed so that the throw is either vertical or horizontal as preferred. Fig. 60 shows a double-pole single-throw switch and a triple-pole double-throw switch correctly placed and a single-pole single-throw switch wrongly placed.

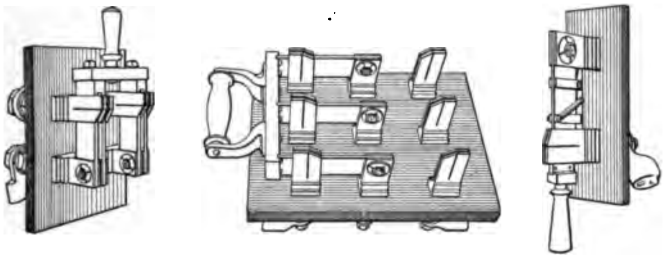


Fig. 60. Single, Double, and Triple Pole Knife Switches

Whenever practicable, knife switches should be so wired that the blades will be *dead* when the switch is open as this leaves less exposed live metal and also makes it easier and safer to make any repairs or adjustments of the switch blades and hinges. In Fig. 61 if the supply wires (from the service or dynamo) enter at the top and the lamps are connected from the bottom of the switch, the blades will be *dead* when the switch is open. If the arrangement is reversed, the switch blades will be connected to live wires all the time, whether the switch is open or closed. The illustration also shows an excellent type of cast-iron cabinet for such a switch combination.

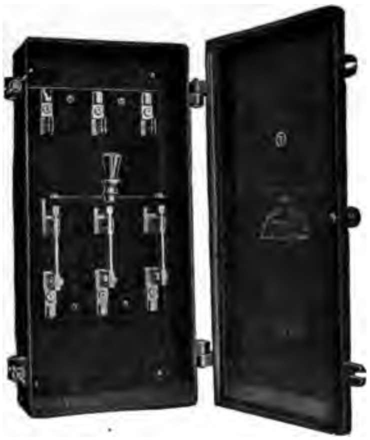


Fig. 61. Approved Metal Switch Box

Surface Snap Switches. These are the common porcelain base switches, usually round in shape and having metal covers with the operating handle at the center. They are commonly mounted on side walls and the wires are brought into them from the back. It is not possible to fasten them very securely to a lath-and-plaster wall unless some block is provided for the screws to be driven into. For this reason, wherever possible, at all switch or fixture outlets, a $\frac{7}{8}$-inch block must be fastened between studs or floor timbers flush with the back of lathing to hold tubes, and to support switches or fixtures. When this cannot be done, wood base blocks, not less than $\frac{3}{4}$ inch in thickness, securely screwed to lathing, must be provided for switches, and also for fixtures which are not attached to gas pipes or conduit. Figs. 62 and 63 show these blocks with the wires brought through them and through the lath and plaster in short lengths of flexible tubing. The switches can thus be firmly screwed to the blocks and the wires connected to them.

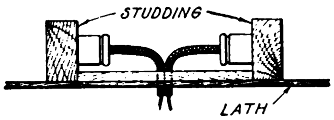


Fig. 62.

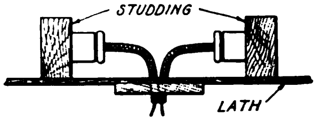


Fig. 63.

Proper Arrangement of Wires Passing through Lath-and-Plaster Partition

If snap switches are used with exposed wiring on cleats, there must be a porcelain sub-base under each switch so made that the wires will be kept $\frac{1}{2}$ inch from the surface wired over. A similar sub-base must be used where such a switch is used with wood molding, but in this case it may be of hard wood instead of porcelain. Figs. 64 and 65 show how this is done.

Flush Switches. These are made to be inserted into walls so that only the operating push buttons or handle will extend out beyond the surface, and are now in very general use. Inasmuch as their operating parts are concealed in the wall they should invariably be set into small steel boxes through the back of which the wires may enter either through lengths of flexible tubing or through iron conduit. The same requirement applies to all small fittings such as receptacles from which flexible cords are run to heaters and other portable devices. Fig. 66 is a sketch of such a switch box set into a lath-and-plaster wall. The sketch shows the box as it would appear from the back of the wall.

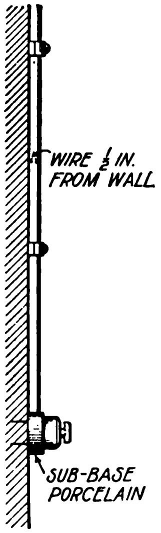


Fig. 64. Exposed Wiring on Cleats

Where it is desired to control the same electric lamps from either of two switches at different places, what are called *three-way* switches are installed. These are chiefly used in residences, as for the control of hall lights from either upstairs or downstairs. Under the rules these are classed as single-pole switches and are preferably wired so that only one main of the circuit is carried to either switch. Three-way switches are usually of the common round-surface porcelain-base type or push-button wall variety. Fig. 67 gives a diagram of the way to connect them.

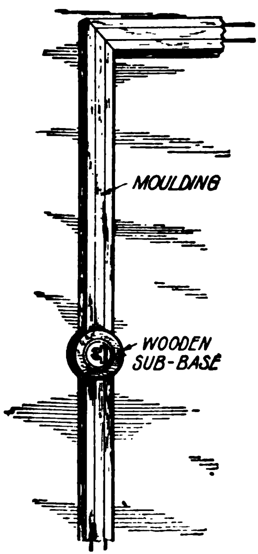


Fig. 65. Wires in Wood Molding

Fuses and Circuit Breakers. These may be compared with "safety valves" on steam boilers, that is to say, they are primarily designed to act in case of an improper condition of affairs and prevent by their automatic action any serious trouble resulting. Although this is the purpose of fuses and overload circuit breakers, it is altogether too common for users of electric current to misuse them, and so disstroy the protection intended. It is evident that a fuse which is so large that it will not melt until a current passes through it which is far too large to be safely carried by the wires or other parts of the circuit, is worthless. The fusible part of a fuse is usually a strip or wire of soft lead or zinc of such size that if any considerable current over that for which it is designed passes through it, it will melt off and so open the circuit. Whenever a fuse of the proper size for its circuit *blows* or *melts*, the first thing to be done is to seek out the cause, for the operation of the fuse is *proof* that there is, or has been, something wrong. Thus if in a house a lighting-circuit is properly protected by 6 ampere fuses and these fuses blow, one may be sure that more than 6 amperes, and, therefore, *more than a safe current* has, for some reason, traversed the wires for a time long enough to melt the small fuse strip. Now, unless this excess of current was due to some momentary accident, known and recognized as such, the same condition that once allowed the unduly large current to flow probably still exists, and until this trouble is sought out and remedied, the same unsafe condition exists. It is, therefore, very unwise to replace the blown fuses with some of larger current-carrying capacity, for this is merely reducing the protection without removing the source of danger.

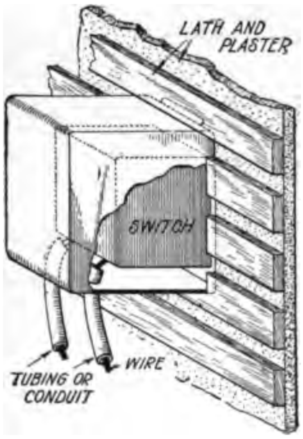


Fig. 66. Flush Switch Box in Lath-and-Plaster Partition

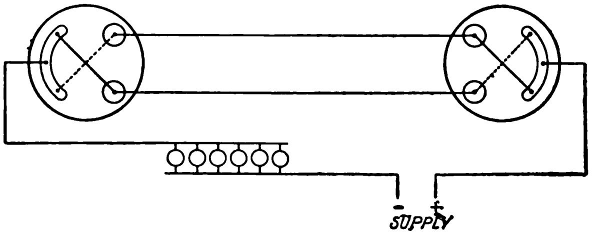


Fig. 67. Wiring Diagram for Three-Way Switch Circuit

Still worse is it to replace blown fuses by fuses which have been filled up with metal, or across, or through which, extra metal strips have been fastened in a misguided attempt to keep the fuses from blowing again. One might as reasonably tie down a steam boiler's safety valve. These principles when thus stated appear very elementary and self-evident and yet the misuse and abuse of fuses is, perhaps, the commonest fault observed in the maintenance of electric installations. The only reason that disaster does not always follow ignorant or culpable misuse of fuses, is to be found in the fact that wires and other parts of the system are installed with a fairly large margin of safety. This does not, of course, in any degree justify over-fusing circuits or tampering with fuses or other safeguards, and insurance inspectors should not tolerate any deviation from standard rules for the protection of circuits or fail to demand the use of only approved protective devices of proper rating for every circuit. Fig. 68 shows some fuses which have been "doctored" in ways unfortunately all too common.

The following excellent statement is taken from the book of rules of the Associated Factory Mutual Companies:

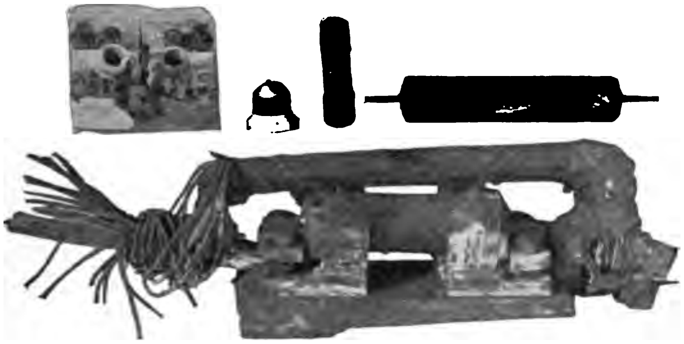


Fig. 68. Typical Examples of "Doctored" Fuses

Specifications for fuses require that they shall be rated at a certain per cent of the maximum current which they will carry indefinitely, as follows: link fuses 80 per cent and enclosed fuses 90 per cent. The margin thus provided between the rating of the fuse and its actual melting point will permit the ordinary fluctuations in current without opening the circuit. If fuses selected to conform to the above rule are not large enough to carry the load, it is evident that the wires also are overloaded, and either the load should be diminished or the size of the wire increased.

Circuit breakers are so sensitive that it is often necessary to set them much above the ordinary current to keep them from being constantly opened by momentary rises in the current, such as might be caused by starting a motor or by a rise in the voltage of the dynamo due to a sudden decrease of load.

When this is the case, a fuse may be necessary to protect the wire from a steady current above the safe carrying capacity of the wire but below the point at which the circuit breaker is set to open. The fuse requires a little time to heat, and so does not melt with the momentary rises of current which would open the circuit breaker if it were set as low as it would have to be if the fuses were not provided.

It has already been pointed out that "service entrances" must be fused, that is, there must be a fuse in each wire where the current supply is brought into a building. An exception is made in the case of three-wire (not *three-phase* a. c., however), systems. In these the fuse may be omitted in the neutral wire, provided this wire is of equal carrying capacity with the outside wires and is reliably grounded, since in such a three-wire system the neutral wire cannot under any condition carry more current than either of the outside wires; the fact that it is grounded adds a certain safety, because it is especially desirable that the neutral should not be opened unless the outside wires are also opened, as might occur if a neutral fuse alone blew, or was removed without the others also opening. Fig. 69 illustrates this point. When the fuse in the neutral at *N* is in place, lamps *A* can have only 110 volts across them and lamps *B* the same, but if the fuse *N* is removed, the group *A* will be in series with the group *B* across the 220 volts of the outside wires, and as there are 4 lamps at *A* and only 2 at *B*, the resistance and volts *drop* across *A* will be only one-half the resistance and drop across *B*. Thus *A* will get only one-third of 220 volts or 73.3 volts, and *B* will get 146.7 volts. The lamps *B* will thus burn *over bright* or even burn out, and those in *A* will be dim. Of course, if there were the same number of lamps at *A* as at *B*, it would make no difference whether the neutral wire were open or not, but when the system is *unbalanced* as in Fig. 69 it is better to avoid having the neutral opened and, therefore,

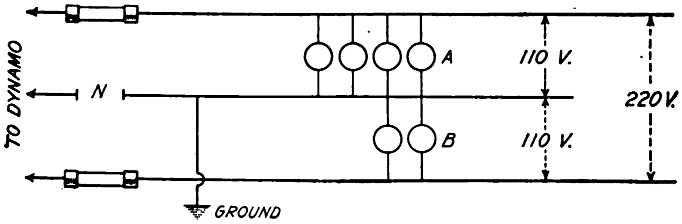


Fig. 69. Fuse Arrangement for Three-Wire Circuit

the fuse in it is often omitted, and the wire carried through unbroken.

Beyond the service entrance fuses and switch, the circuits are usually divided; thus in a house several circuits of smaller wire will lead to the lights on the different floors, or in a larger building or a factory, sub-mains will be carried up to the distributing centers through the building from which in turn smaller wires will branch out. The proper proportioning of these cables and wires for the economical distribution of current is a problem for the electrical engineer. The point to be noted here is that fuses or breakers must be placed at every point where a change is made in the size of wire unless the fuse next back will also protect the smaller wire. The rated capacity of fuses must not exceed the allowable carrying capacity of the wire as given on page 65, and circuit breakers must not be set more than 30 per cent above the capacity of the wire unless a fuse is also used, when they may be set 100 per cent higher. Fig. 70 shows the sizes of wire and the fuse arrangement for a typical case. The arc lamps require 30 amperes, the 20 incandescent lamps 10 amperes, and the motor has a full load current of 20 amperes. The motor, however, must have leads for 25 per cent above full load current or 25 amperes or No. 10 wire. Allowing 60 amperes for the total normal current the service fuses at A might be 60 amperes and the wires next beyond them No. 4. The other wire sizes are shown and the fuses would have to be placed as shown and have the following

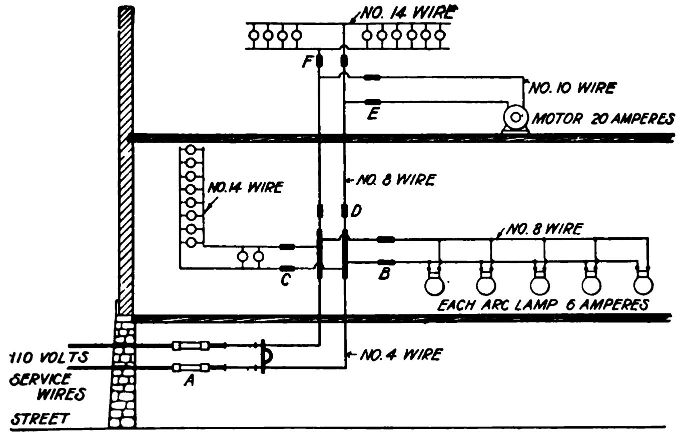


Fig. 70. Diagram Showing Fuse Arrangement and Size of Wire for Typical Lighting and Power Circuit

ratings: *B*, 30 amperes; *C*, 10 amperes; *D*, 30 amperes; *E*, 20 amperes; and *F*, 10 amperes. The 10-ampere fuses are required at *C* and *F*, because by a special rule mentioned below this is the limit for fuses for branch circuits at 110 volts supplying incandescent lamps. A pair of fuses is also required for *each* arc lamp and these would in the case shown usually be of a 10-ampere rating. If circuit breakers were substituted for the motor fuses at *E* they should be set to open at not over 30 per cent above the capacity of No. 10 wire or about 31 amperes.

It will frequently be found necessary to provide cut-outs where taps are taken from large mains. In such cases, if the clamps on the cut-outs are not sufficiently large and strong to give a firm and secure connection, a short length of smaller wire may be soldered to the main wire and then carried direct to the cut-out, which should be located as near as possible to the point of connection with the mains. Special care should be taken to guard these leads from accident as they may not be properly protected by the fuses in the main circuit.

Fuses are always installed in pairs (or sets of 3 on three-wire circuits), so that each side of the circuit is fused for the reason that a "ground" or "cross" might occur so as to cause a large current to flow over a path not including any fuse. Furthermore, fusing both sides gives a much greater factor of safety and insures protection under all conditions.

In installing incandescent lamps, fuses must be so placed that no set of lamps requiring more than 660-watts power will be dependent on a single pair of fuses. Some city rules state this in terms regulating lamp sockets or receptacles, and limit the number of such sockets since this amounts to about the same thing. The purpose of this rule is to secure such a subdivision of the fuses that no very large currents can flow for any long time over any part of the small wiring without opening a fuse and thus the effects of a short-circuit or other accident will be very much minimized. Suppose we had a long line of No. 10 wire protected by 25 ampere fuses on a 110-volt circuit, and 50 incandescent lamps in multiple on this line with no other fuses. Suppose also that only one of the lamps were burning. Now if this lamp were hung on a flexible cord and a "short-circuit" occurred on the cord or in the lamp socket, we should have to wait until the short-circuit became severe enough to allow about 30 amperes of current to flow before the 25-ampere fuses would open. (All fuses will carry, for a short time, more than their rated currents.) But 30 amperes at 110 volts may cause an arc quite intense enough to set fire to the cord or cause molten metal to drop from the overheated socket. If the lamps were on a branch circuit of No. 14 wire protected by 10-ampere fuses, these fuses would probably melt before serious harm were done. Thus it may be seen that it is wise to subdivide the lamp circuits and protect each circuit with small fuses. In exposed wiring in large mills an exception is made permitting incandescent-lamp circuits with 25-ampere fuses to be used provided *each lamp* is protected by a very small fuse placed in a ceiling rosette. This is allowed to prevent running an excessive amount of wiring through large rooms where the crowded wires might be themselves a source of danger. It was formerly the custom to place small fuses in the canopies of fixtures or ceilings and side walls but they were always troublesome and dangerous to an extent that did not offset the slight extra protection they afforded and all such "bug" fuses have long been forbidden.

Enclosed fuses, plug and cartridge, are allowed by the Code rules to be installed without cabinets except in dusty or linty places but some municipal ordinances require *all* fuses to be in cabinets. While this is safer, there would be a tendency to use the open-link lead fuse everywhere if cabinets were universally required since they are much cheaper than enclosed fuses, and this is a tendency not to be encouraged. If proper locations are chosen for enclosed fuses and if only approved fuses are used, there is little hazard under ordinary conditions. Enclosed fuses either of the cartridge or the plug type and of makes having the underwriters' approval will open the circuits for which they are rated with practically no explosive action and without emitting flame or molten metal even on heavy short-circuits. Even so, however, they should never be placed near combustible material.

Electric Heaters. Under this heading are included all devices in which use is made of the heat developed by the current (usually by causing it to pass through coils of wire). These are electric pressing irons, air and water heaters, toilet articles, such as curling irons, cooking devices of all sorts, and a vast and constantly increasing variety of domestic and industrial appliances. All these present the same hazards as other heaters of equal capacity, except that the dangers of open gas flames and of matches are eliminated, and they all require the same precautions in use and in their installation. Each should be protected by fuses on the device, or preferably in the branch circuits, and must be controlled by separate switches or plug connectors so made as to indicate whether the current is "on" or "off." These must be double-pole switches if more than 660 watts of energy is required. In general, such heaters should never be "built in" but should be in plain sight. However, for many industrial purposes electric heaters are constructed as parts of tools or machines and when well made and used with due care are not more hazardous than other methods of heating.

Portable heaters are in general more dangerous than stationary ones since the latter may be safeguarded by suitable heat-resisting material placed between the device and its surroundings, such as sheets of tin or steel with an air space between them or by alternate layers of sheet steel and asbestos with a similar air space.

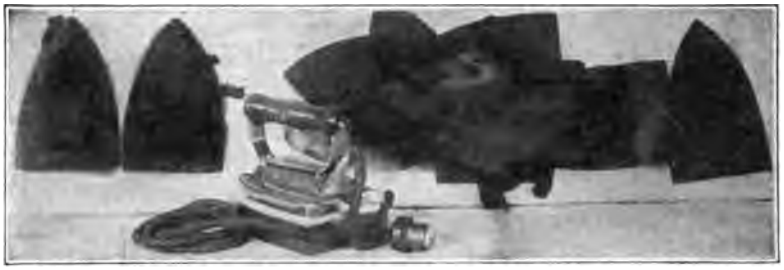


Fig. 71. Effects of Careless Use of the Electric Iron

The electric flatiron is perhaps the cause of more trouble and danger from fire than any other form of heater. The temperature of the iron required for ironing damp fabrics is necessarily high (at least 500° F. is common) and if the iron is left with current *on* and is not in use it will become red-hot in from ten to twenty minutes. If it has been left on a table or on clothing a fire is almost inevitable. Fig. 71 shows a cloth-covered board burned by electric irons. Few irons have any automatic cut-off to guard against such an accident and the fact that many such irons are used by persons not familiar with the possible danger, makes these devices rather hazardous.

It is often desirable to connect in multiple with the heaters and between the heater and the switch controlling same, an incandescent lamp of low candle power, as it shows at a glance whether or not the switch is open, and tends to prevent it being left closed through oversight. An approved stand, of a pattern such that the iron may be safely left on it even with the current on, should be used with every electric pressing-iron. The ordinary plain iron stand for cast flatirons is not adequate as it will become hot enough to set fire to a table. It should be remembered that stove-heated irons get cooler when taken from the stove, while an electric iron will get hotter and hotter if left connected to the circuit and not used. Fig. 72 shows an iron properly installed with indicating switch, pilot lamp, and stand.

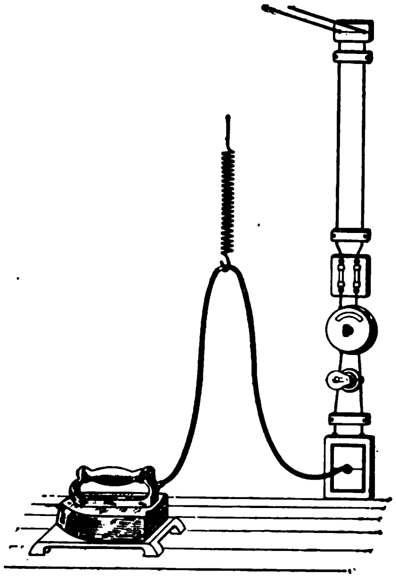


Fig. 72. Properly Installed Electric Iron Circuit

Portable heaters, if they require over 250 watts, should be furnished with approved "heater cord" which consists of stranded copper conductors with a thin rubber and a thick asbestos yarn covering over each with a good braid over all. In factories and shops where a large number of flatirons or rather portable electric heaters are used, the circuits leading to them should be so arranged and provided with switches that any department or tier of benches can be cut off when not in use and pilot lamps in conspicuous places should be provided to call attention to the fact that the circuit is closed to the heaters. Domestic cooking devices electrically heated, are, in general, fairly safe as made by well-known manufacturers, and are preferable from the viewpoint of fire hazard to similar appliances heated by gas or by alcohol lamps.

The use of flatirons or other heaters on ordinary lighting circuits is undesirable since they often require more current than can be taken through the proper fuses for such lamp circuits. It is very desirable that special circuits be run of large wire properly fused and with large capacity fittings and that all heating and small power devices such as washing and vacuum cleaning machines be supplied from such special circuits. The ordinary wall or ceiling fixtures and the lamp sockets attached are very ill suited for connecting portable heaters because of their lack of current-carrying capacity; and, too, because they are not mechanically strong enough to withstand the comparatively rough usage to which such connections are inevitably subjected.

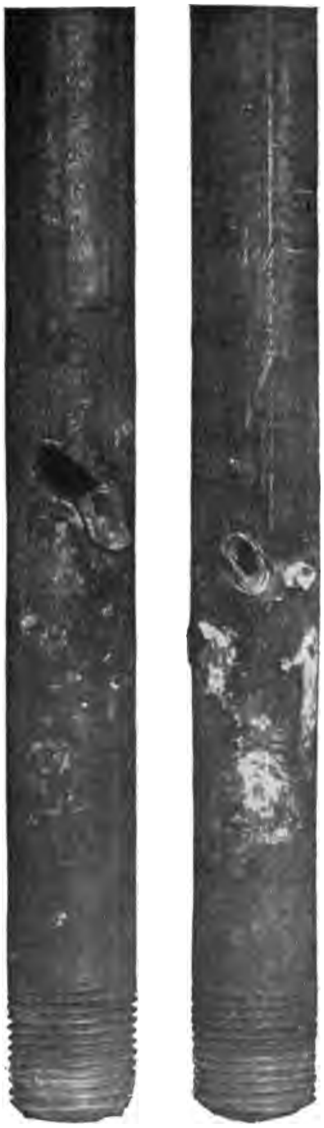
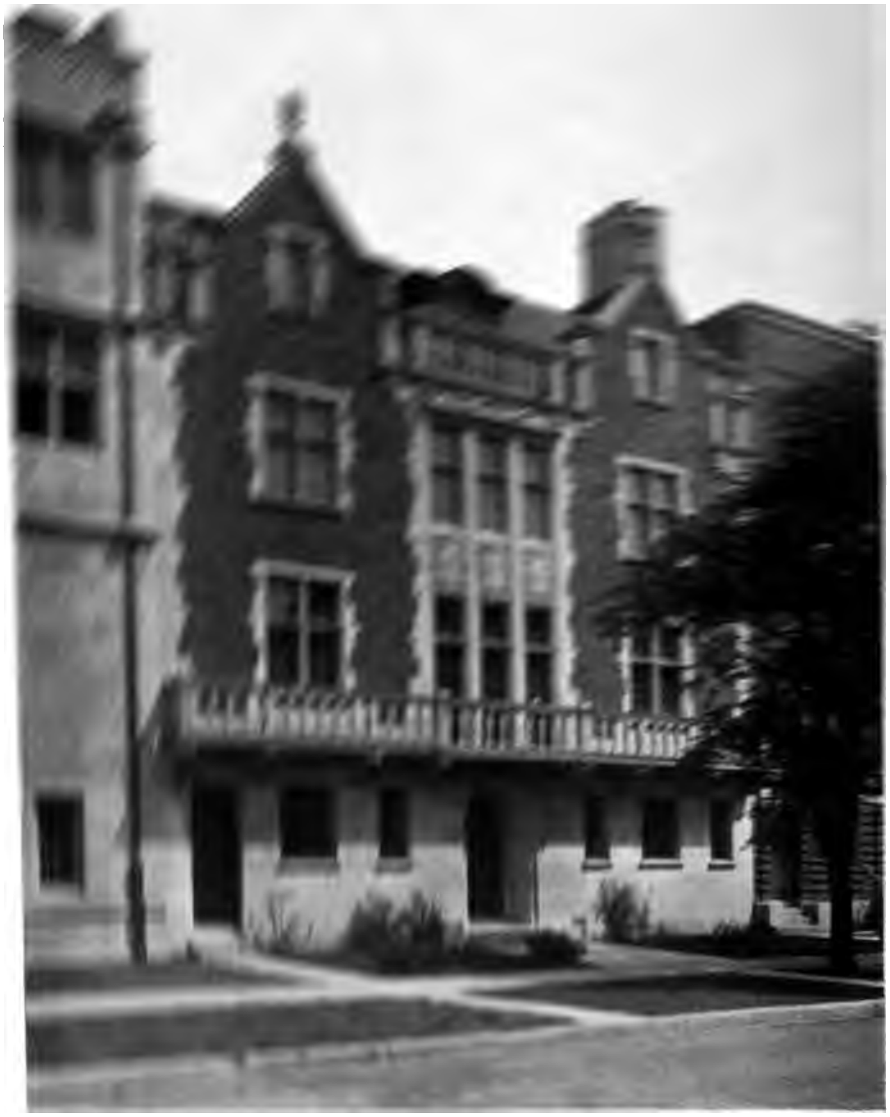


Fig. 73. Punctures in Gas Pipes from Short-Circuits

FIXTURES AND FIXTURE WIRING

Fixture Details. Electric fixtures are of two types known as straight electric and combination, the former carrying only electric lamps and the other having both electric and gas lights. The chief parts of a fixture are the canopy at ceiling or wall, the stem, the body, the arms, and the sockets. Most fixtures consist of pipes, often of small size, which are threaded into special castings in the body or central ball with arms branching from the body.

In straight electric fixtures the wires are usually drawn through the pipes, but in combination fixtures the gas runs in the pipes and the wires lie along the outside of the pipes between them and an outer casing or are drawn through cored holes in cast-brass arms. The necessarily small spaces and channels for wires in fixtures and the slight amount of insulation which the wires can carry, require very careful work in order that the best conditions possible may be maintained. The pipes in which wires are drawn should



THE HOUSE OF MR. T. DONNELLEY, ASTOR STREET, CHICAGO

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be carefully reamed at ends and all sharp angles, burrs, and corners on which wires may be injured should be carefully rounded off. These details should be attended to by the fixture maker but are often neglected, resulting in such accidents as are shown in Fig. 73, where the current has burned holes through the gas pipe and ignited the gas. Nothing but rubber-covered wire having a rubber wall, and no wire smaller than No. 18 B. & S. gauge, should be used. Stranded wire is preferable to solid wire. A rubber insulation $\frac{1}{64}$-inch thick is permitted on No. 18 wire for fixtures, but all No. 16 wire and all flexible cord if used for fixture work should have at least $\frac{1}{32}$-inch wall. Fixtures are not allowed on circuits of over 300 volts.

Insulating Joint. On lath-and-plaster ceilings and walls where steel outlet boxes are not used, fixtures are usually fastened to some form of "crowfoot," a small tripod casting into which the stem of the fixture is screwed. Combination fixtures are screwed on the projecting nipple of the gas pipe. When fixtures are thus supported on gas pipes or when they are attached to any grounded metal work of a building or are on walls or ceilings of plaster on metal lathing, an approved "insulating joint" must be inserted between the fixture and its support. An insulating joint is a coupling, the two ends of which are reliably insulated from each other by some substance, such as mica. For combination fixtures there is a hole for the gas through the center of the joint. Such joints are required to be made of materials which will not be affected by the gas; no soft rubber is allowable and they must be capable of withstanding a voltage test of 4,000 volts a. c. between the two ends. Such insulation is required because the fixture wire is necessarily poorly insulated and liable to permit the conductors to become "grounded" on the fixture at one or more points. The insulating joint prevents such a failure in the fixture from causing current to flow to the earth in case the circuit is either purposely or accidentally grounded at other places. It also prevents voltage sufficient to puncture the fixture wiring from arcing across broken insulation to the fixture and so to the ground.

Canopy Insulators. Since the canopy or bell covering the base of the fixture at the ceiling or wall is in electrical connection with the fixture stem, it also must be insulated at its upper edge from the wall wherever an insulating joint is required. Canopy insulators take the form of molded rings of composition, fiber rings riveted to the canopy edge or insulating linings and flanges of micanite or other suitable material. Fig. 74 shows a correctly mounted combination fixture with insulating joint and canopy insulator. The cut also shows the pieces of flexible tubing in which the wires are separately encased from the last porcelain support, through the ceiling and to a point below the insulating joint. *B* in the figure is a piece of insulating tubing which should be placed about the gas pipe above the insulating joint. In case the wires were in steel conduit a steel outlet box would be placed in the ceiling, the gas pipe would enter through a central hole in the back and the conduit through another hole at one side. In such cases the flexible tubes would not be used but the canopy insulator and the insulating joint would still be required. Most trouble from fixtures occurs in the canopy from poorly made wire joints and crowded or jammed wires which gradually give way until finally an arc is formed and the wire coverings are ignited, Fig. 75. Canopies are often made too shallow and too small and workmen are often careless in connecting fixtures.

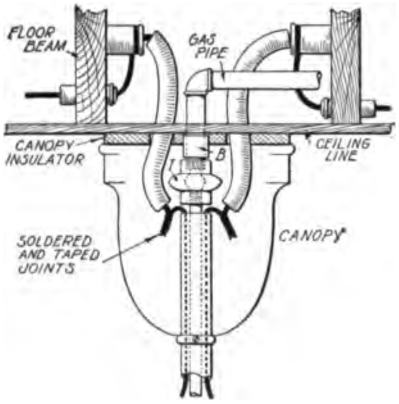


Fig. 74. Correctly Mounted Combination Fixture

Sockets and Receptacles. These are the devices into which incandescent lamps are put and are today made in a great variety of forms. The most common is the familiar brass shell socket either with a key switch or keyless, screwed on the ends of fixture arms or hung on flexible cords. Where a lamp holder is desired to be fastened rigidly to walls or ceilings, receptacles are used and this in general constitutes the distinction between receptacles and sockets. For outdoor use or in damp places weatherproof sockets or receptacles should be used. These usually have porcelain or composition outer shells, with connecting wires sealed in or with some form of encased terminal so placed and covered as to keep moisture from exterior and interior.

It is good practice to use only porcelain sockets in locations where a person might touch them while at the same time in contact in any way with any grounded metal work. Thus in bath rooms if a person attempted to turn on a lamp by means of the key of a brass covered socket while at the same time he was touching a water pipe or faucet, he might receive a painful or dangerous shock if any portion of the electric circuit were grounded. While such a shock would not be given, if everything were in proper condition, still there are numerous instances where persons have been killed and it is certainly wise to prevent even the chance of such an accident by either using all porcelain sockets or by putting the sockets out of reach, and controlling the lamps by means of a switch on a side wall. This practice is especially to be commended where the lamps are supplied with a. c. transformers the primaries of which are supplied by circuits

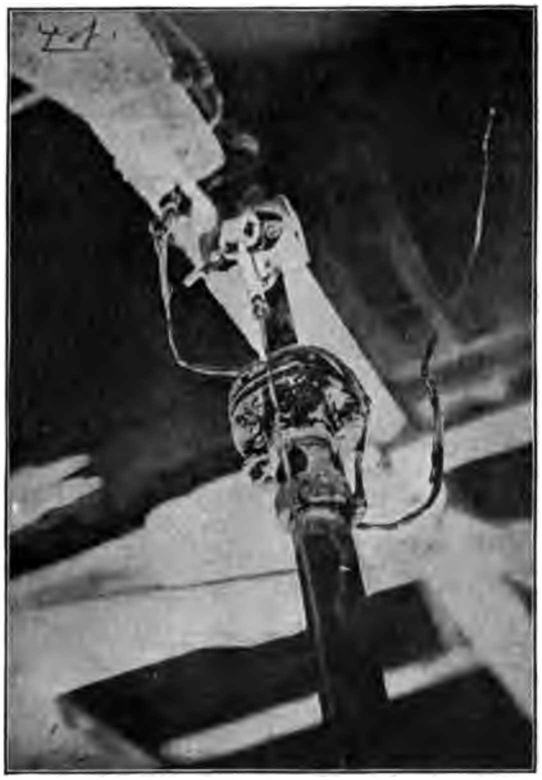


Fig. 75. Result of Defective Fixture Insulating Joint

of voltages of 1,100, 2,200, or higher values. The voltages of 110 or even 220 either d. c. or a. c., which are almost universally used for incandescent lighting indoors, are not of themselves at all liable to injure persons, but if there is a fault in the transformer the high primary voltage may get into the house over the secondary lines and such a circuit will then be distinctly dangerous to life.

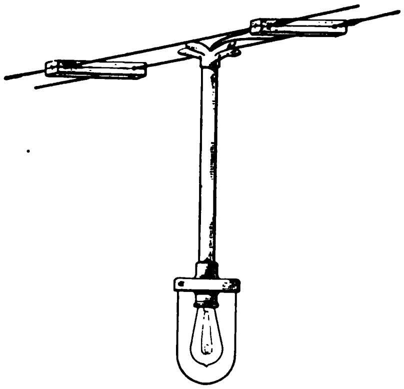


Fig. 76. Enclosed Incandescent Lamp as Precaution Against Explosive Vapor

In rooms where inflammable gases may be present, as the result of some manufacturing process or otherwise, the incandescent lamp and its socket must be enclosed in a vapor-tight globe and supported on a pipe hanger, wired with approved rubber-covered No. 14 wire soldered directly to the circuit wires. Even the minute spark caused by breaking a 16-candle-power lamp has been known to set fire to vapors such as gasoline and air in the proper mixture and the reason for taking every precaution against sparks where such vapors exist, becomes very apparent. Fig. 76 shows a lamp so enclosed and supported.

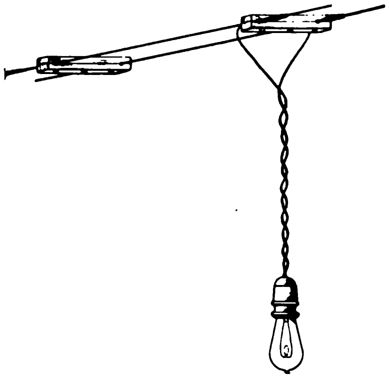


Fig. 77. Flexible Cord Mounting for Incandescent Lamp

In damp or wet places weatherproof sockets are required and these must either be made upon fixtures or hung as shown in Fig. 77. Here stranded No. 14 rubber-covered wires are shown passing from the socket to the circuit wires to which they are soldered. The socket and lamp must not hang direct on the soldered joints but some other support must be supplied as by holding the socket wires under one of the porcelain cleats. The ordinary brass shell socket is a fairly standard device as now furnished by the best makers, but it is of necessity small, and not very strong. It is decidedly better never to use such a socket except for an incandescent lamp and where an outlet is desired from which to take current for portable heaters, fans, and the like, to provide special wall or floor receptacles. This insures adequate current-carrying capacity and avoids mechanical injury to the comparatively frail sockets.

Flexible Cords. There are two chief classes of flexible cords, the plain twisted pairs and the various types of reinforced cord for portable use and where extra protection and strength is needed. It will be observed that the use of *any* type of flexible cord constitutes an exception to the general rule that conductors must be well separated. From one point of view it seems inconsistent to require wires to be well separated in walls, floors, and partitions and then permit the two conductors of a cord to be twisted closely together, with only a thin rubber insulation and a cotton braid on each. It is, in fact, a concession made to the necessities of the case and it cannot be denied that flexible cords may be and often are the weakest part of an ordinary wiring installation. It thus becomes at once evident why very definite limitations must be made in the use of cords. Fig. 78 shows types of flexible cords.

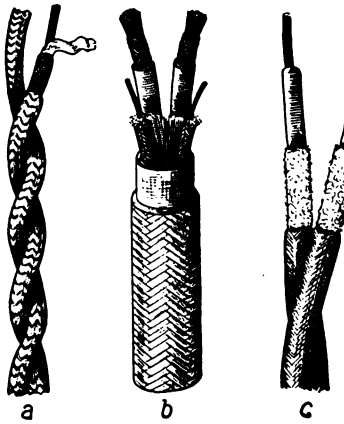


Fig. 78. Types of Flexible Cords

The common "twisted pair" cord consists of stranded copper conductors having a total carrying capacity equal to that of No. 18, 16 or 14 B. & S. gauge solid wire. No conductors smaller than No. 18 are allowed even for very small currents in order that the mechanical strength may not be too little. (It should be noticed also that No. 18 and No. 16 wires are permitted only for flexible cord and for fixture wiring, No. 14 or larger being required everywhere else.)

The copper strands are twisted or cabled together and wound with a wrapping of cotton thread both to keep the rubber from direct contact with the copper which it tends to corrode and to prevent a broken strand of wire puncturing the insulation.

The rubber insulation should be $\frac{1}{32}$-inch thick on No. 18 and No. 16, and $\frac{3}{64}$-inch on No. 14 cords and over each should be a fairly close braid of cotton thread. It is apparent that the finished cord so made with its two conductors twisted closely together does not afford any very great protection against a short-circuit resulting from broken or worn insulations and braid, and that the rubber and cotton braids supply a very fairly good fuel for any flame which is started.

The foregoing is not intended to lead to the conclusion that flexible cords should not be used, but rather to point to the reason why their use should be restricted and why they are open to objections not applying to ordinary separate and fixed wires.

Flexible cord should never be used as a substitute for regular fixed wiring. If the wiring provided does not give outlets at the proper places it should be changed in a proper and reliable manner. The common practice of festooning flexible cord along walls and ceilings and even through doorways and walls is to be strongly condemned as an unsafe and wholly inexcusable misuse of material. The use of flexible cord is limited to 300 volts. It should not be used to support lamp clusters as they are not capable of being secured well enough under binding screws to hold any considerable weight. The ordinary cord should be used only to hold lamps which under all usual conditions hang freely in air and which are not likely to be moved sufficiently to come into contact with surrounding objects. In brief, this cord is for "pendant" use only as its common name implies. The use of pendant cord for reinforced cord is a very common fault. Ragged half-broken lamp cord lying about on floors and looped over all kinds of supports constitutes a very common defect in installations, otherwise perhaps in fair condition. "Flexible cord fires" are as common as might be expected from the frequent misuse of this form of wire.

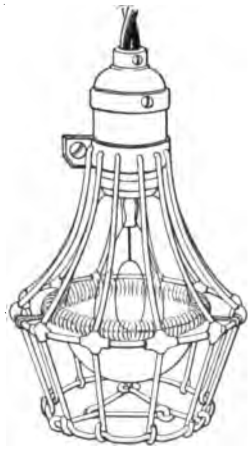


Fig. 79. Wire Guard for Portable Lamp

For all portable work including those pendants which are liable to be moved about, some form of reinforced cord should always be employed. In these the ordinary pendant cord is covered either with an outer rubber jacket and a stout "over-all" braid or where the exposure to injury is less (as in offices and residences) with an outer woven braid only. These reinforced cords are far from indestructible and should be frequently inspected and renewed before an accident makes it absolutely necessary. The use of all kinds of flexible cord in show windows is expressly forbidden by the Code, because it has been found that it is subject to exceptionally hard usage there, and more especially because of the practical certainty that it will be used as a support for window decorations or goods of inflammable nature which have often been found *pinned* to it or supported by wires strung across it. A special kind of cord having a metal armor is, however, allowed in show windows.

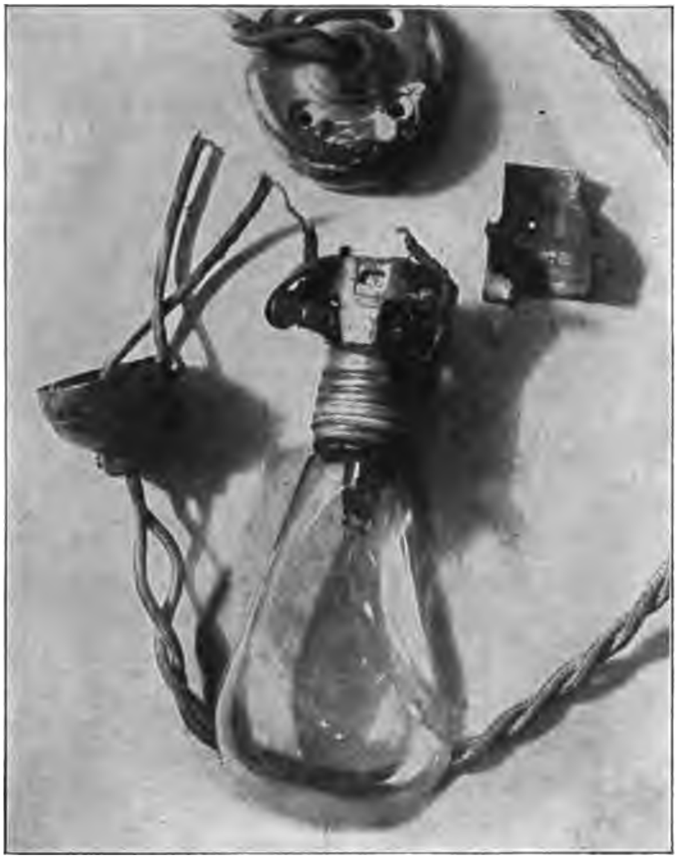


Fig. 80. Results of Careless Handling of Portable Lamps

In connecting flexible cords to sockets, rosettes or other devices, special attention should be paid to seeing that all the small copper strands are well tucked in under the heads of binding screws and that stray ends are not left sticking out to cause short-circuits. At all places where cords pass out of sockets or other fittings, smooth, well-rounded insulating bushings should be provided and a knot should be tied in the cord inside the socket cap or rosette, so that this knot will take the strain from the binding screws. Several special little fittings for this purpose are also on the market as substitutes for the knot. Pendant lamps wherever exposed to injury or at all liable to be brought into contact with inflammable material, and *all* portable lamps should be provided with substantial wire guards such as are shown in Fig. 79. Figs. 80 and 81 show the results of carelessness with hanging or portable incandescent lamps.

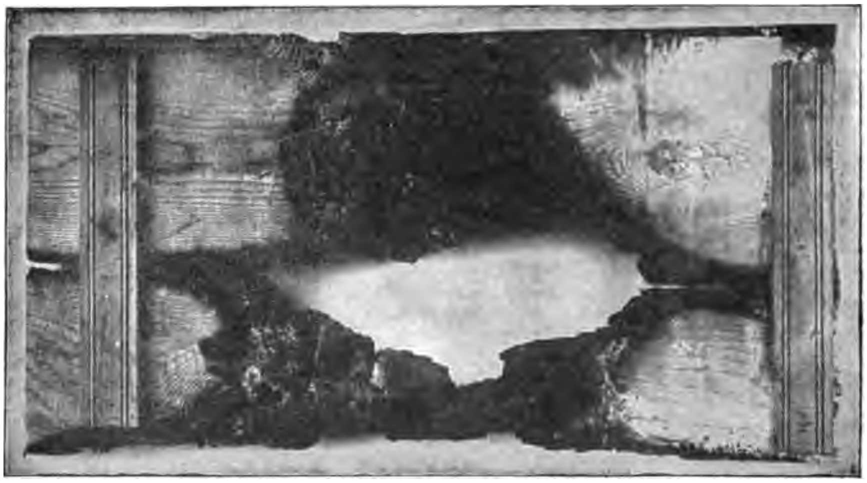


Fig. 81. Hole Burned by Incandescent Lamp Bulb

Arc Lamps on Constant-Potential Circuits. Each lamp, or each series of lamps, should be separately fused and the branch conductors should have a carrying capacity about 50 per cent in excess of the current required to provide for the heavy current required by the lamp in starting or when the lamp carbons accidentally become stuck. If this were not done it would be necessary, generally, to over-fuse the wires, which is objectionable.

Arc lamps are of many patterns but all of them contain resistances or regulators which become very hot and, therefore, all the parts of the lamp and its case must be of non-combustible material and must be treated as sources of heat, that is, they must be installed well away from all inflammable stuff. The globes and netting about the carbons must be used in all cases. In general the resistances and all other accessories of the lamp except the controlling switch should be contained in the lamp case itself. Fig. 82 shows a modern type of enclosed arc lamp and its mechanism.

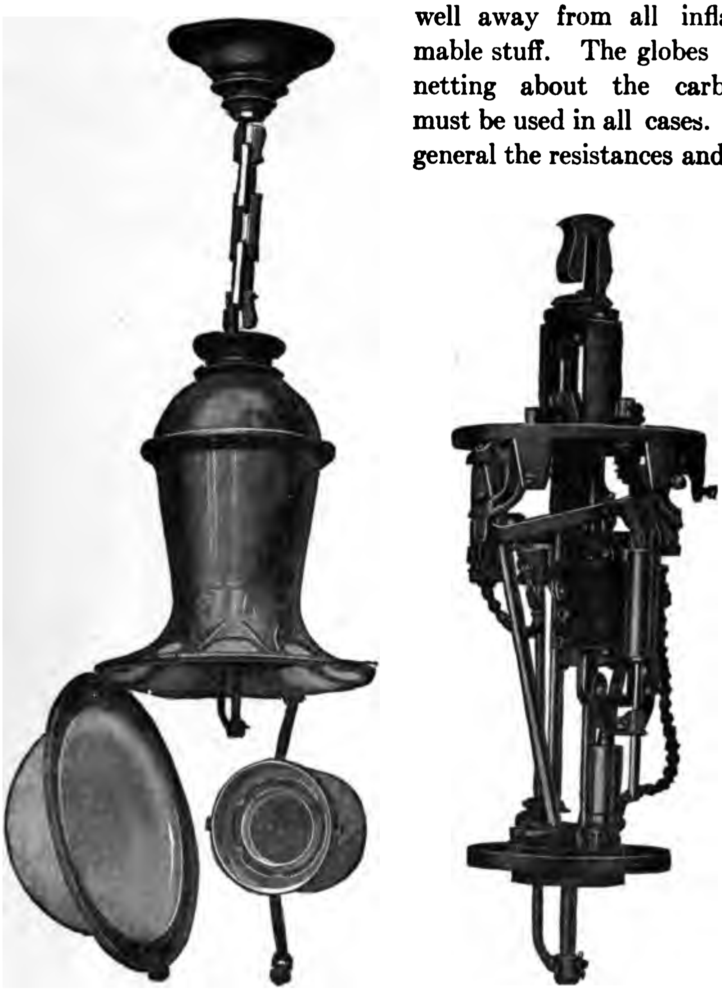


Fig. 82. Exterior and Interior View of Enclosed Arc Lamp

The "flaming arc" lamps now in common use call for the same precautions as the older patterns. In dusty or linty places special precautions must be taken to prevent the accumulation of lint, etc., either on hot resistances, inside the lamp or on the switch usually furnished on the lamp. In general the same rules apply to mercury arc lamps as to the carbon arc lamps, except that the former do not present the hazards due to the hot carbon points.

TRANSFORMERS IN BUILDINGS

Except in central stations and substations, an outside location for transformers is always preferable and the underwriters do not allow any oil-cooled transformers in buildings except by special permission. This is because of the danger from the oil which may be boiled over or set on fire in case the transformer becomes overheated.

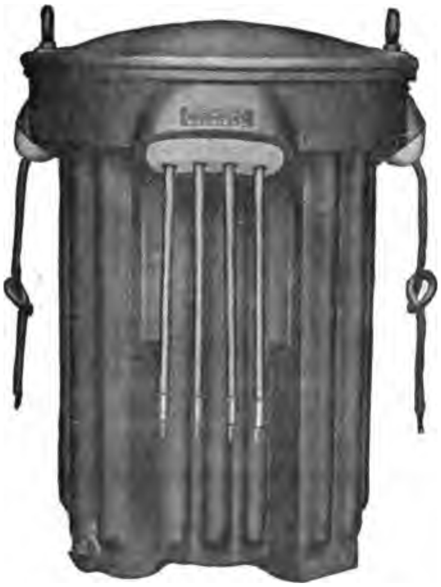


Fig. 83. Common Type of Oil-Cooled Transformer

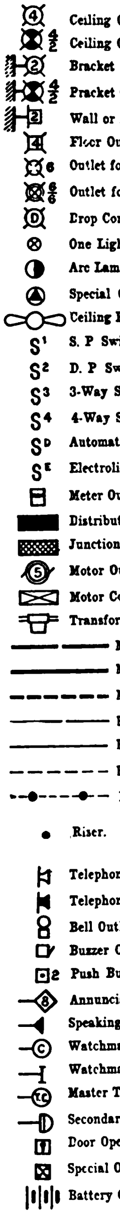
Air-cooled transformers having the highest voltage of both primary and secondary under 550 volts may be installed inside buildings if the case is kept at least one foot from combustible material or separated from such material by being mounted on a suitable slab of slate or marble. Transformers sometimes become very hot in case of a partial or complete burn-out of the coils or from overloading and, therefore, should never be mounted directly against wood posts, beams, or walls. Fig. 83 shows a common type of oil-cooled transformer.

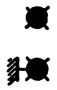
STANDARD SYMBOLS FOR WIRING PLANS

AS ADOPTED AND RECOMMENDED BY

THE NATIONAL ELECTRICAL CONTRACTORS ASSOCIATION OF THE UNITED STATES and THE AMERICAN INSTITUTE OF ARCHITECTS,

Copies may be had on application to the Sec'y of The Nat. Elec Cont. Assoc'n, Utica, N. Y., and the Sec'y of The American Instit. of Architects, Washington, D. C.





Ceiling Outlet, Electric only. Numeral in center indicates number of Standard 16 C. P. Incandescent Lamps

Ceiling Outlet, Combination. 4/2 indicates 4-16 C. P Standard Incandescent Lamps and 2 Gas Burners. If gas only

Bracket Outlet, Electric only. Numeral in center indicates number of Standard 16 C P. Incandescent Lamps.

Bracket Outlet, Combination. 4/2 indicates 4-16 C. P Standard Incandescent Lamps and 2 Gas Burners. If gas only

Wall or Baseboard Receptacle Outlet. Numeral in center indicates number of Standard 16 C. P Incandescent Lamps.

Floor Outlet. Numeral in center indicates number of Standard 16 C. P Incandescent Lamps.

Outlet for Outdoor Standard or Pedestal, Electric only. Numeral indicates number of Stand. 16 C. P Lamps.

Outlet for Outdoor Standard or Pedestal, Combination. 6/6 indicates 6-16 C. P Stand. Incan. Lamps; 6 Gas Burners.

Drop Cord Outlet.

One Light Outlet, for Lamp Receptacle.

Arc Lamp Outlet.

Special Outlet, for Lighting, Heating and Power Current, as described in Specifications.

Ceiling Fan Outlet.

S. P Switch Outlet.

D. P Switch Outlet.

3-Way Switch Outlet.

4-Way Switch Outlet.

Automatic Door Switch Outlet.

Electrolier Switch Outlet.

Show as many Symbols as there are Switches. Or in case of a very large group of Switches, indicate number of Switches by a Roman numeral, thus: S^1 XII, meaning 12 Single Pole Switches.

Describe Type of Switch in Specifications, that is, Flush or Surface, Push Button or Snap.

Meter Outlet.

Distribution Panel.

Junction or Pull Box.

Motor Outlet, Numeral in center indicates Horse Power.

Motor Control Outlet.

Transformer

Main or Feeder run concealed under Floor

Main or Feeder run concealed under Floor above.

Main or Feeder run exposed.

Branch Circuit run concealed under Floor

Branch Circuit run concealed under Floor above.

Branch Circuit run exposed.

Pole Line.

Riser.

Telephone Outlet, Private Service.

Telephone Outlet, Public Service.

Bell Outlet.

Buzzer Outlet.

Push Button Outlet; Numeral indicates number of Pushes.

Annunciator. Numeral indicates number of Points.

Speaking Tube.

Watchman Clock Outlet.

Watchman Station Outlet

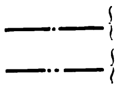
Master Time Clock Outlet.

Secondary Time Clock Outlet.

Door Opener.

Special Outlet; for Signal Systems, as described in Specifications.

Battery Outlet.



Circuit for Clock, Telephone, Bell or other Service, run under Floor, concealed.
Kind of Service wanted ascertained by Symbol to which line connects.

Circuit for Clock, Telephone, Bell or other Service, run under Floor above, concealed.
Kind of Service wanted ascertained by Symbol to which line connects.

NOTE—If other than Standard 16 C. P. Incandescent lamps are desired, Specifications should describe capacity of Lamp to be used.

SUGGESTIONS IN CONNECTION WITH STANDARD SYMBOLS FOR WIRING PLANS

It is important that ample space be allowed for the installation of mains, feeders, branches and distribution panels

It is desirable that a key to the symbols used accompany all plans.

If mains, feeders, branches and distribution panels are shown on the plans, it is desirable that they be designated by letters or numbers.

Heights of Centre of Wall Outlets (unless otherwise specified)

Living Rooms	5′ 6″
Chambers	5′ 0″
Offices	6′ 0″
Corridors	6′ 3″

Height of Switches (unless otherwise specified) 4′ 0″

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UNDERWRITERS' REQUIREMENTS

PART II

INSTALLATION OF WIRES IN BUILDINGS

The proper choice of wires and their safe installation constitutes the most important part of all electric equipment from the viewpoint of the fire hazard. It has already been stated that in all electric work, conductors, however well insulated, should always be treated as bare, and from one point of view, it may be said that the value of conductors as regards safety lies in their insulation rather than in the copper, for if we assume that a wire of adequate carrying capacity is chosen for a given purpose, there remains only the choice of a suitable covering or insulation on the wire and a reliable and workmanlike method of placing it.

No one material has yet been produced which has every desirable property as a covering and insulation of electric wires and cables. Among the desirable properties of a wire covering are elasticity, flexibility, waterproofness, good insulating quality and resistance to voltage strains, resistance to effects of changing temperature, acids, vapors, etc., and permanence. All of these properties are possessed by rubber in greater or less degree and, all told, to a greater degree than any other material. The properties of rubber-covered wires will be treated at greater length in another place, the foregoing statement being made here to emphasize the reason why rubber-covered wires are used almost exclusively in all inside wiring.

"Slow burning" wire is a copper conductor covered with three closely woven cotton braids saturated with a fire-resisting compound. Its use is limited to places where rubber is liable to be rapidly injured by high temperatures. Its insulating value is slight and it is not capable of resisting moisture.

"Weatherproof" wire consists of a copper conductor covered with three braids saturated with a moisture-proof compound. Its insulating value when new is low (much less than rubber) and it is very inflammable. Its use is practically confined to outdoors.

In the following sections it may be assumed that all references to wire mean "rubber-covered" wire.

Classification and General Principles. There are two classes of wiring which may be named for convenience: *enclosed* wiring and *non-enclosed* wiring.

Wires run on insulators such as cleats and knobs exposed on walls and ceilings or on knobs and through tubes concealed in floors and walls are the chief types of non-enclosed wiring. It will be observed that the distinction consists in the presence or absence of special wire-ways or channels for the wires. Wires must not be laid in plaster, cement, or similar finish, because such materials may contain either alkalies or acids which will injure the insulation and corrode the copper. Wires must never under any circumstances be fastened with staples because of the probable injury to the wire coverings, the insecure fastening obtained, and the possibility of such staples affording a path between wires in case twin conductors are used.

Twin wires must never be used except in conduit or where flexible conductors are necessary. The nearness of the two wires, on the opposite sides of the circuit, renders twin wire of any description somewhat more liable to failure and an injury to one wire generally involves an injury to both with resultant certainty of a short-circuit. The added safety of keeping the wires of a circuit separated is lost in twin wires.

In any scheme of wiring it is essential that all electric wires be installed so that they cannot come into contact at any point with any materials other than those expressly intended for their enclosure or support. This means that they should be kept absolutely free from contact with gas, water, or other piping, and from all metal work of any description unless it be that of piping, boxing, or molding provided as wire enclosures. Wires should also be installed so as not to touch woodwork or other combustible material, even if such material is not a good conductor. This general principle finds an exception in the case of wood molding.

Contact of wires with metallic substances may, in case of a failure of the insulation, permit dangerous arcs, short-circuits, or grounds, while contact with wood or combustible material is objectionable on account of setting fire to it in case of overheated wires or from leakage due to the presence of moisture on materials which when dry would be good insulators. These are, therefore, the general principles of wiring under the established rules and will be illustrated in the discussion of the various classes of wiring which follow.

Open Work in Dry Places. Wires in open work may be either rubber-covered, slow-burning, or—special and now little used wire having a weatherproof braid covered by a slow-burning braid—but as a matter of fact only rubber-covered wire is used to any extent and it is much to be preferred except in exceptionally hot places as over steam boilers, where rubber insulation will deteriorate very rapidly. The rubber-covered wire used for open work has a single braid over the rubber. The chief advantages of open work are its cheapness and its accessibility. The latter may be of great advantage in cases where frequent changes and additions are likely to be required or where renewals of wire are frequent because of peculiarly unfavorable conditions such as exist in packing houses.

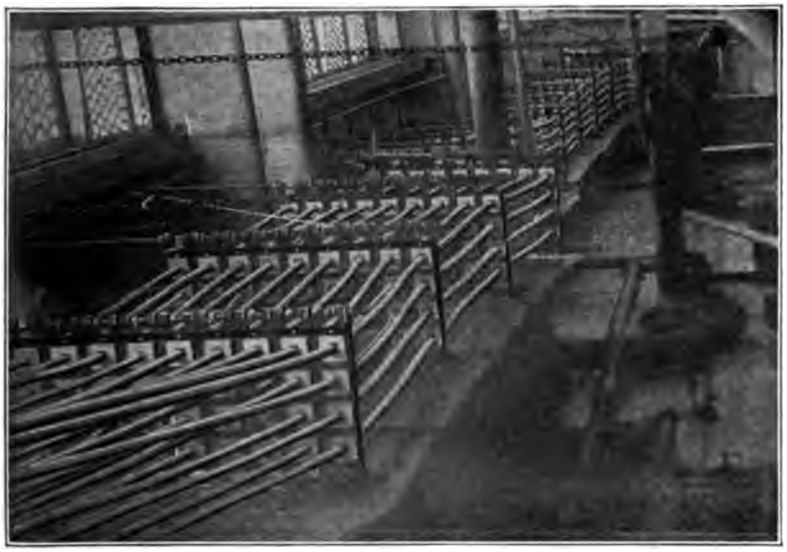


Fig. 84. Large Feeder Wires Exposed on Insulators

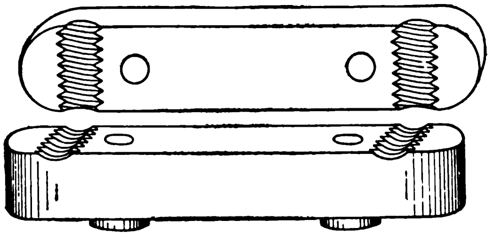


Fig. 85. Porcelain Two-Wire Cleat

Open work finds its chief use in mills and factories and for large conductors which it is especially difficult and expensive to enclose in conduit. Fig. 84 shows an example of a set of large feeders run exposed on insulators. It should be noted that such a large group of heavy cables covered with the inflammable braid and rubber insulation furnishes a very considerable amount of fuel for fire and the necessity for excellent spacing and reliable fastening is obvious. The heavy porcelain blocks carried in metal frames as shown in the illustration are of an approved type. In all open work, wires or cables must be rigidly supported on non-combustible, non-absorptive insulators. Formerly wood cleats were used but these are now obsolete and have been replaced by porcelain. Where the voltage is less than 300 volts, wires must be separated from each other at least 2½ inches and from the surface wired over at least ½ inch in dry places—in damp places at least 1 inch. For voltages from 301 to 550 volts, the limit for "low-potential systems," the wires must be kept 4 inches apart and 1 inch from the surface wired over.

Split knobs or cleats must always be used for the support of conductors which are smaller than No. 8 B. & S. gauge except when they are found at the end of runs. Fig. 85 shows a typical form of a two-wire cleat and Figs. 86 and 87 show good

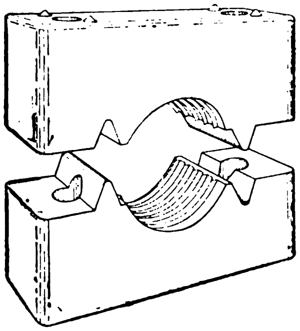


Fig. 86. Porcelain One-Wire Cleat

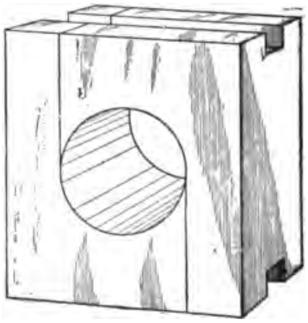
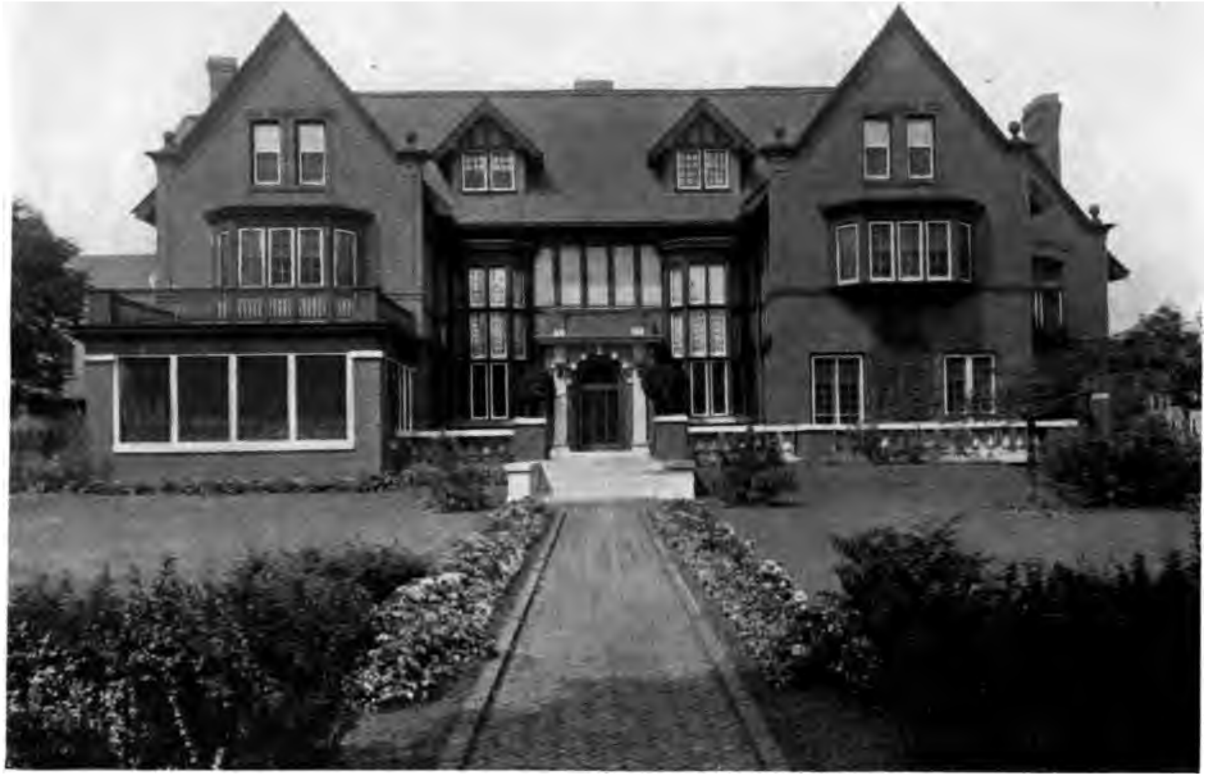


Fig. 87. Porcelain One-Wire Cleat



RESIDENCE OF ERNEST RECKITT AT EVANSTON, ILLINOIS
Ernest Mayo, Architect, Chicago

forms of one-wire cleats for heavier conductors. No. 6 wire is about the largest which should be installed in cleats like those in Fig. 85, and for cables larger than No. 0000 B. & S. gauge, some form of iron rack for the insulators is desirable in order to secure the needed mechanical strength and rigidity.

The rigid supporting necessary for open wiring requires under ordinary conditions along flat surfaces, supports at least every 4½ feet. This distance should be decreased wherever wires are liable to be disturbed especially if the wires are small. The following comment is from the Rules of the Associated Factory Mutual Fire Insurance Companies:

> The proper distance between insulators depends largely on the surroundings. In places where ceilings are low, or where belts, shafting, or other machinery may require frequent attention, insulators should be placed every few feet, in order to prevent the wires from being displaced by careless or unavoidable blows from workmen. On the other hand, with a high ceiling and no chance of derangement, a greater distance would be allowable.
>
> The whole idea is to so rigidly secure the wires that they cannot come in contact with each other or any other conductors, if loosened by shrinkage of timbers and floors or by careless knocking.

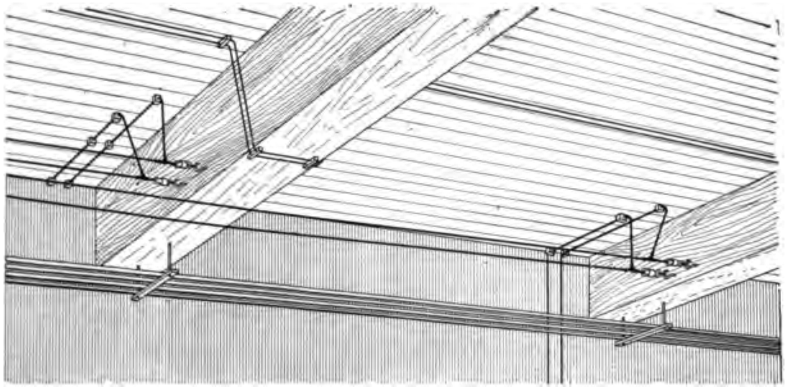


Fig. 88. Wiring on Ceiling Showing Use of Strain Insulators

Special methods must be followed at corners and in wiring over broken surfaces as on ceilings of mill-constructed buildings. Fig. 88 shows a use of "strain insulators" in making a turn on a ceiling. These are insulating balls having rings set in each side, the wire being looped through one ring and the hook on the beam through the other. Turnbuckles may be used to keep the wires taut. Ordinary cleats will not hold heavy wires at corners. With conductors of No. 8 B. & S. gauge or over, it is not necessary to "break around" beams but smaller wires should be carried around the beams as shown in Fig. 89. The cleats on the ceiling should be set off from the timbers 3 or 4 inches. If they are closer, the shrinkage of the timber or rough usage is liable to bring the wires into contact with the timber. On the other hand if the distance is greater, the wires are too much exposed to injury from brooms, ladders, and the like. With this arrangement any slack wire can be taken up by moving the cleats a little nearer the corner. Where beams are widely spaced some such method of support as that shown in Fig. 90 should be followed. Fig. 91 shows a less desirable method of support. In low ceiling rooms where wires are exposed to mechanical injury, wood guard strips (see Fig. 92) may be used to advantage. Where wires pass through partitions or walls they must be protected by tubes of porcelain or iron pipes lined with flexible tubing.

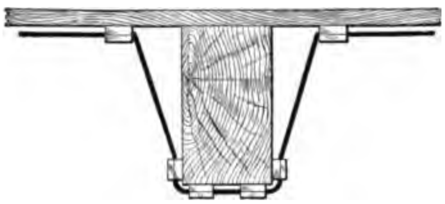


Fig. 89. Approved Method of Carrying Wires Around Beams

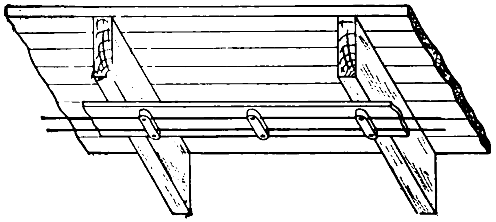


Fig. 90. Method of Running Wires between Widely-Spaced Girders

Wires on side walls must be protected from injury to a height of at least 5 feet from the floor either by wood boxing or by iron pipe as shown in Figs. 93 and 94. When iron pipe or conduit is used the insulation of each wire must be reinforced by flexible tubing extend-

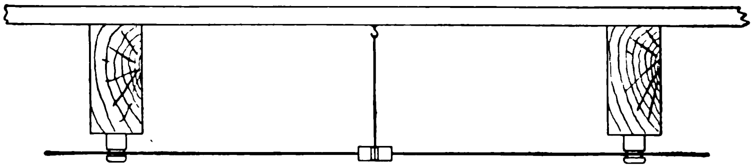


Fig. 91. Method of Avoiding Sag between Widely-Spaced Girders

ing from the insulator next below the pipe to the one next above it (see Fig. 93). For alternating current both wires of the circuit must be in the same pipe.

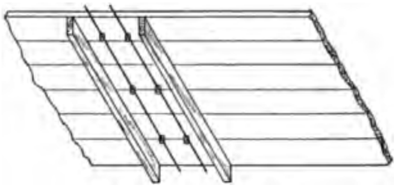


Fig. 92. Diagram Showing Use of Guard Strips

Open Wiring in Damp Places. The installation of electric wires in places exposed to dampness presents some peculiar difficulties requiring special methods. A film of water such as may be formed by steam or otherwise by condensation is a very fair conductor of electricity, and may reduce or even entirely destroy insulation which would be quite adequate in dry places. Acid or alkaline fumes or vapors are also good conductors in some cases and in addition they are liable to injure both the insulators and the copper of electric wires.

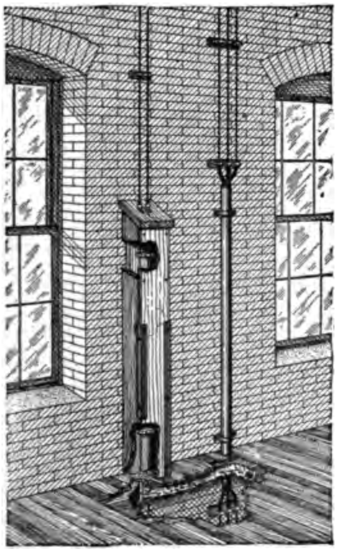


Fig. 93.* Wood Boxing as Protection for Wires on Side Walls

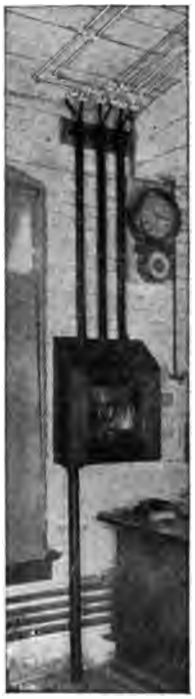


Fig. 94* Protecting Wires on Walls by Iron Piping

In paper mills, breweries, soap factories, packing houses, dye works, and cold storage rooms special pains must be taken to insure permanence and reliability of all electric fittings and appliances.

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* *Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.*

The Code does not prescribe at length precautions to be taken in damp or otherwise exceptionally troublesome places, but merely specifies for open wiring that only rubber-covered wire be used and that the separation between wires shall be at least 2½ inches for voltages up to 300 volts (4 inches for higher voltages) and that all wires be kept *1 inch* from surface wired over instead of only ½ inch as in dry places.

There are two objections to the use of steel conduits in damp places, *first*, that all metal work is especially liable to corrosion even when well enameled or galvanized; and *second* and *more important*, that water is apt to collect in the pipes and gradually deteriorate the insulation. This water results from moisture condensed from the air during changes in the temperature and amount of water vapor present in the atmosphere. This condensation is often sufficient to be very troublesome and often leads to the adoption of open wiring of special forms rather than a complete conduit installation. Usually conduit is used in the more exposed or crowded places only and in such parts of the plant as are less liable to dampness.

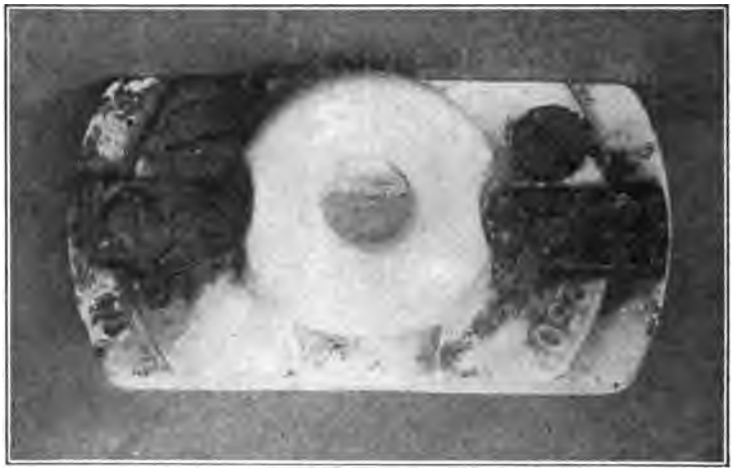


Fig. 95. Corroded Rosette Improperly Mounted on Damp Ceiling

In many breweries, packing houses, and other plants, walls and ceilings are continually dripping with water and in some factories fumes and vapors are present in large quantities at all times. A fairly good solution of the problem is possible where only water is to be guarded against, but where corrosive vapors exist, no thoroughly satisfactory method has been devised to resist indefinitely the corrosive actions. A good asphaltum paint will protect cabinets and conduits for a time and frequent repainting will extend the life of these parts of the equipment for a considerable period. It is evident that current-carrying metal parts should be enclosed in tight boxes wherever feasible and very frequent and thorough reinspections of the entire equipment should be made followed by renewals as faults develop. Fig. 95 shows the corrosion on a rosette improperly mounted.

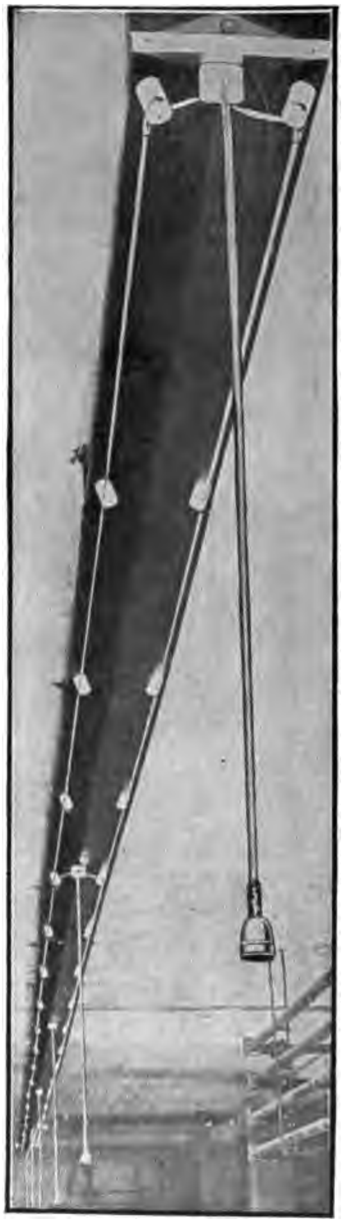


Fig. 96. Inverted Troughs on Damp Ceilings

In rooms where dampness is excessive the wires are sometimes run open in inverted wood troughs, one form of which is shown in Fig. 96 and in detail in Fig. 97. This trough serves to separate the wireway entirely from a wet ceiling and the sloping surfaces serve to carry the moisture away from the knobs on which the wires are held. The **V**-shaped blocks are spaced about 4½ feet apart and care is taken to make a close joint where the running boards come together at the top. The whole is thoroughly painted with an insulating paint. Fig. 98 shows open wiring on flat running boards for moderately damp places like basements or cellars.

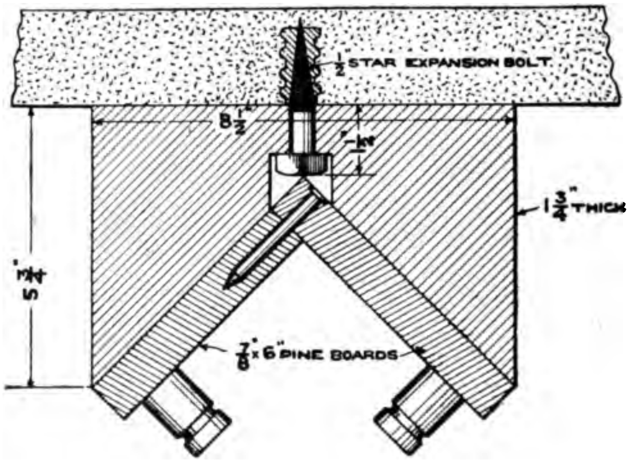


Fig. 97. Section of Wiring Trough

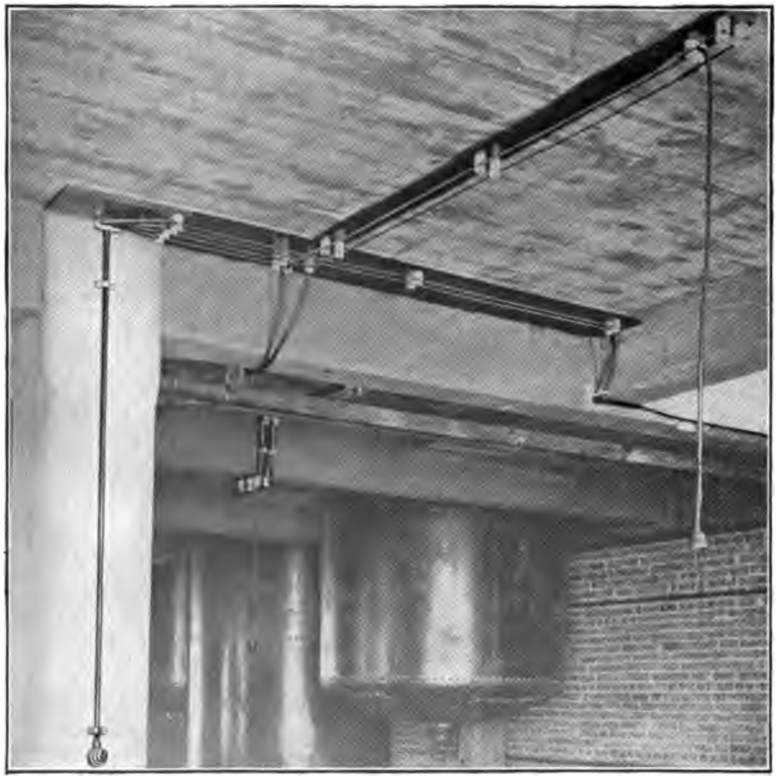


Fig. 98. Example of Wiring on Running Boards in Damp Place

All drop cords should be of extra heavy reinforced type or of standard rubber-covered wire and only weatherproof keyless sockets should be used with all wire joints soldered, taped and painted in the best manner. Motors and their resistance boxes or starters should be kept out of damp rooms if possible but if in such rooms, they should be installed with special reference to accessibility, cleanliness, and separation from wet floors or walls. Posts in middle spaces of rooms will generally afford better locations than side walls, which are always wet. Wood cabinets lined with slate or with stiff asbestos board are preferable in many wet places to metal enclosures if they are kept well painted inside and out with an asphalt or insulating paint. A single incandescent lamp in such a cabinet if kept constantly burning will tend to keep the interior of the box dry, if the box is tight and if the door is kept closed. With a glass panel in the door the lamp may be seen at all times.

Wires in Molding. *Wood Molding.* Wood molding is one of the commonest forms of protection for wiring and when properly used affords a cheap and fairly satisfactory installation. From one point of view it seems inconsistent to take every precaution in other forms of wiring to keep wires away from direct contact with wood surfaces, such as ceilings and walls and hidden spaces in frame partitions and floors, and on the other hand to permit them to be run in small grooves in strips of wood, as in molding work. The solution to this somewhat theoretical objection is found in the fact that in molding, the wires are completely enclosed in a wire-way especially designed for them, rather than allowing them to hang or be drawn over wood objects in a more or less accidental manner with no real protection, and a still better solution is to be found in the unquestionable fact that the use of molding under proper conditions has proved generally satisfactory. The use of wood molding is, however, prohibited in many large cities by local ordinances.

Wood molding should *never* be used in concealed spaces or in damp places or for voltages over 300. The rule as to damp places precludes its use in cellars and basements, anywhere out-of-doors and generally on outside brick walls which are often more or less damp and likely to "sweat" and thus introduce moisture back of the molding. If the wood molding becomes soaked with water there is a liability of leakage of current from one conductor to the other or to "ground." If conductors in molding become overheated by excess current the wood may become charred, and charred wood is a fair conductor. The possibility of fire from such a cause is evident.

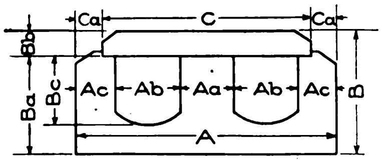


Fig. 99. Section of Two-Wire Molding

Molding should be made of hard wood and should be thoroughly impregnated inside and out with a paint- or moisture-repellant. It must be made in two pieces, a backing containing the wire grooves, and a capping. The tongue between wires must be at least $\frac{1}{2}$ inch thick and the wood under the grooves must be at least $\frac{3}{8}$ inch thick. Figs. 99 and 100 give the forms of two- and three-wire moldings. Larger moldings are sometimes used for heavier wires but generally only small conductors are placed in wood moldings. Only good rubber-covered wire should be used and no joints or splices made in the wires in the molding, but where branch taps are necessary some form of fitting approved for the purpose should be employed. Such fittings as the one shown in Fig. 101 provide porcelain bases with suitable binding screws for the main and the branch wires and a cover over the joints.

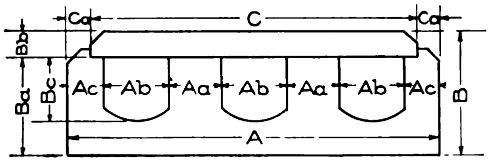


Fig. 100. Section of Three-Wire Molding

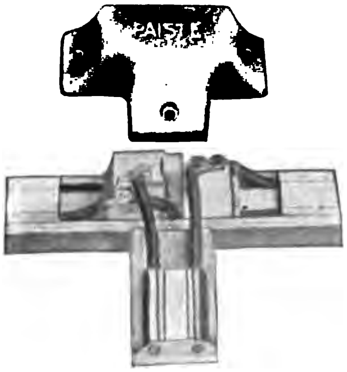


Fig. 101. Device for Making Tap in Molding

A large variety of receptacles (both for lamps and plug connectors), rosettes, etc., are available for use with wood molding and should be used instead of the ordinary patterns. Where it is desired to insert a snap switch, either a special switch approved for mounting directly on the molding, or else a sub-base of porcelain or hard wood on which the switch can be securely fastened should be employed.

Wood molding is often used in connection with other types of wiring and in such cases special attention should be given to making a good mechanical job where the conductors enter or leave the molding. Fig. 102 shows one form of protector for use in protecting wood molding at floor levels. The capping should be carefully and tightly nailed in place and under no circumstances should fixtures be attached to molding or any hooks or nails be driven into it for the support of lamp cords or other objects. The use of wood molding in show windows is undesirable: *first*, because of the dampness apt to exist there; and *second*, because in the process of decorating windows and arranging displays of merchandise nails will surely be driven into the molding with resultant injury to the insulation of the wires.

In conclusion, it may be said that wood-molding work is cheap and may be used properly, but is inferior to most types of wiring.

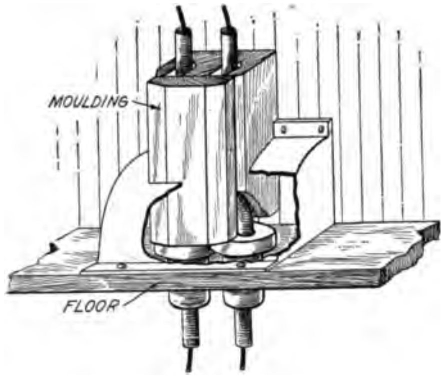


Fig. 102. Molding Protection at Floor Level

Metal Molding. Recently several types of *metal molding* have been introduced which are free from some of the objections adhering to wood molding, and make possible a neat, inexpensive, and convenient installation. In these moldings, as in those of wood, the wire is *laid in*, not drawn in as in conduits, and is covered by a metal capping. At present the underwriters' rules limit its use to circuits requiring not more than 1320 watts of energy.

Special fittings are provided for angles, bends, taps, and crosses, and for switch, rosette, and receptacle bases. The molding can be bent for slight curves or offsets and when carefully installed gives good results. Fig. 103 shows such a molding and fittings.

Metal molding must be continuous from outlet to outlet and where it passes through floors it must be enclosed in an iron pipe for added protection. The backing must be secured by screws or bolts with heads countersunk so as not to obstruct the wire-way. Between lengths of molding and at all fittings and outlet boxes the joints must be mechanically and electrically secured. The fundamental idea is to secure an absolutely continuous metallic conductor throughout the entire run of molding and in addition the molding must be well grounded in a permanent manner. In this respect the molding is regarded in the same light as rigid metallic conduit. The reasons for requiring good electrical continuity and grounding will be explained later when the subject of conduit is considered.

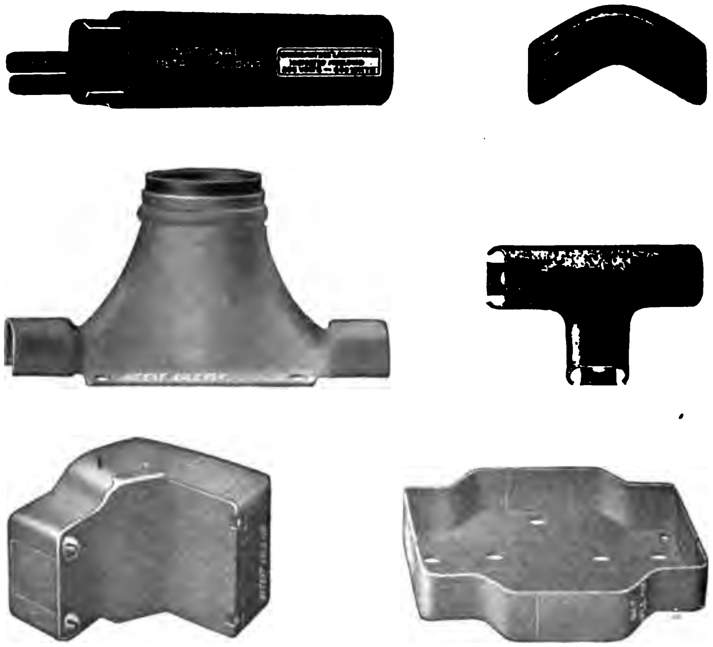


Fig. 103. Metal Molding and Fittings

Concealed Work. This kind of wiring is also often called "knob and tube" work since the wires are held on knobs and passed through tubes of porcelain. The great advantage of this method of wiring consists in the cheapness and ease with which a building, especially a frame building, can be wired. The greatest objection to the knob and tube work lies in the fact that the wires are wholly unprotected from mechanical injury and the building is not protected from the results of arcing between wires in case of a cross or short-circuit.

It is no doubt true that knob and tube wiring is the least reliable form of electric work and inferior to good conduit or armored cable. Where wires can be run open and are not exposed too much to mechanical injury, they are probably somewhat safer than when concealed on porcelain supports in walls, floors, and partitions. Open wiring is not possible in residences or where good appearance is a requisite, and the somewhat greater cost sometimes prevents the use of conduit. Therefore, recourse is made to concealed wiring and where an installation is carefully made a reasonably good result may be obtained. In many cities concealed work is entirely forbidden within "fire limits", that is, in the closely-built sections, but it is still very extensively employed in places where first cost and quickness of installation are the prime factors. Only good rubber-covered wire is allowable in concealed work.

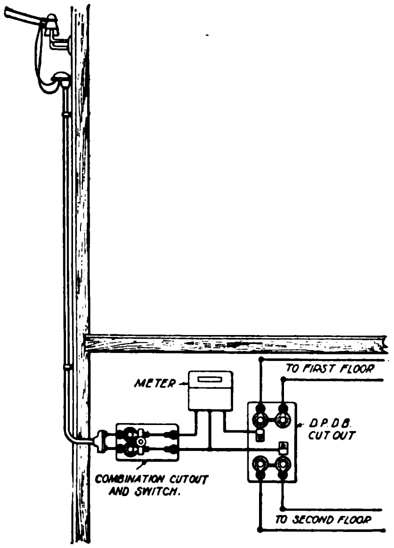


Fig. 104. Approved Wiring System on Entering Building

Approved Installation in a Residence. The wiring of a residence may be taken as an illustration of how the work should be done. The service wires are brought in through the wall near the ground preferably in iron conduit but allowably through bushings with drip loops outside, Fig. 104. As near as practicable to the point of entrance is placed the main service fuse and switch. These should be in a suitable cabinet though this is not obligatory. It should be understood that the wiring is placed during the erection of the building. In an ordinary frame building the wiring will be done just after the rough flooring and the partition studding has been placed, but before the lathing or any plastering is done. It should all be completed except the final connection of service wires, fixtures and fittings before any of it is enclosed or hidden, so that inspection may be made while all parts are accessible and visible.

From the service cabinet and meter as many circuits are run as may be required to feed the lamps and other devices to be connected, each being fused at the service center unless there is no change at that point in the size of wires. These circuits will pass up through the floor within porcelain tubes and will thence be carried on porcelain knobs fastened to the timbers and studding not more than 4½ feet apart. Where the wires pass through floor timbers, porcelain tubes, straight and smooth, must be used in holes bored in the wood and just large enough for the tubes. In general we may say that knobs are used where the wires run parallel with floor beams, and tubes where the wires are run at right angles to the beams. Fig. 105 shows the general method and Fig. 106 illustrates a two-piece knob. These are required for wires less than No. 8 B. & S. gauge and are preferable to one-piece knobs which need a tie-wire. The wires should be run singly on separate timbers and must, except as noted below, be kept

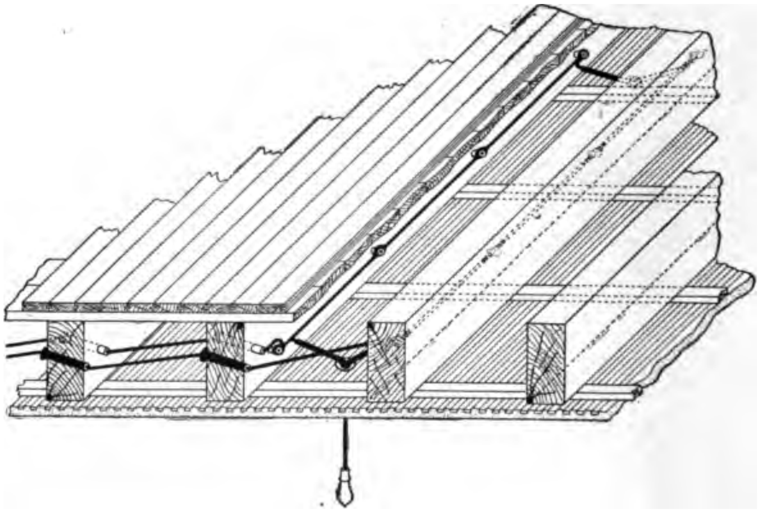


Fig. 105. Knob and Tube Wiring in Floor

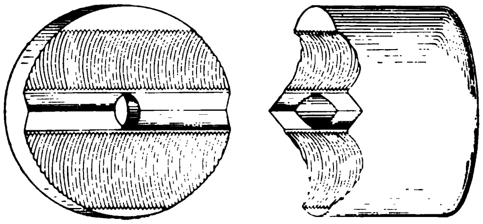


Fig. 106. Two-Piece Knob for Holding Wire

everywhere 5 inches apart. Fig. 107 shows clearly the use of the knobs and tubes, but the tubing shown on two of the upper wires is objectionable and knobs should have been used instead. It is very desirable to use metal outlet boxes at *all* outlets and the added expense of so doing is not large. Where flush switches or receptacles

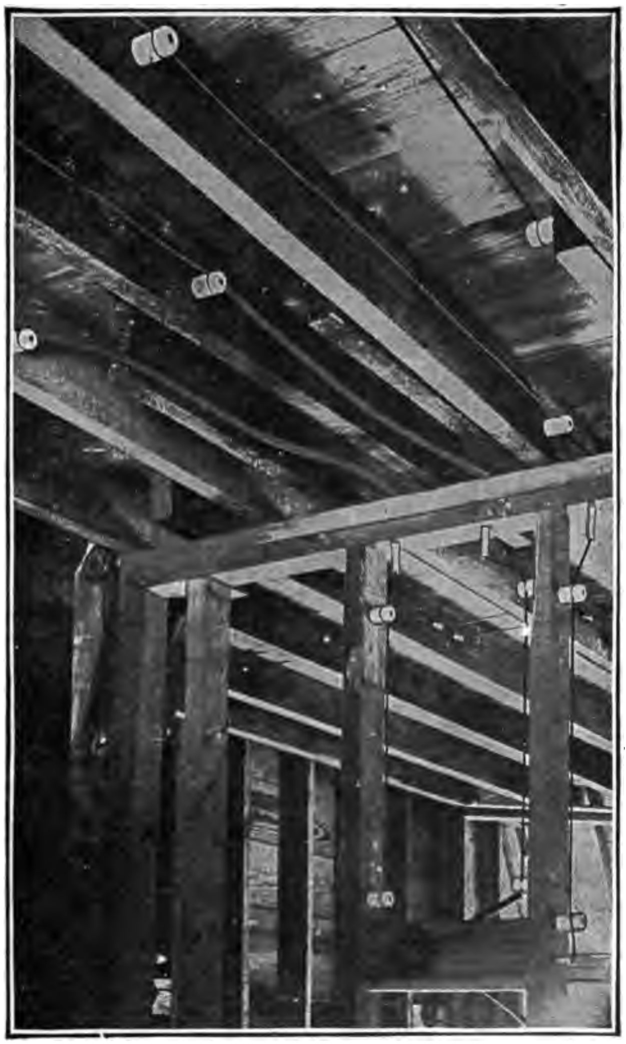


Fig. 107. Knob and Tube Wiring Showing Objectionable Features

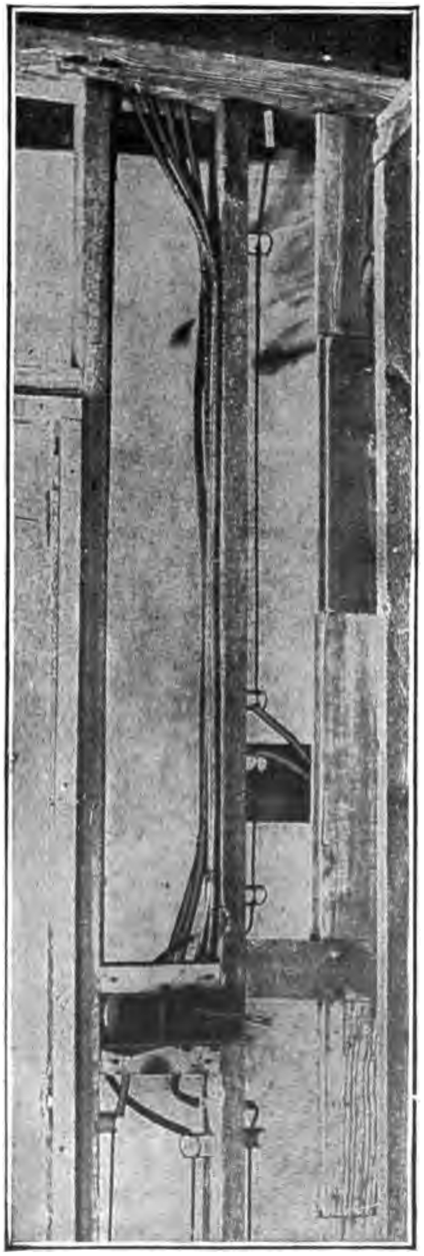


Fig. 108. Proper Use of Outlet Boxes

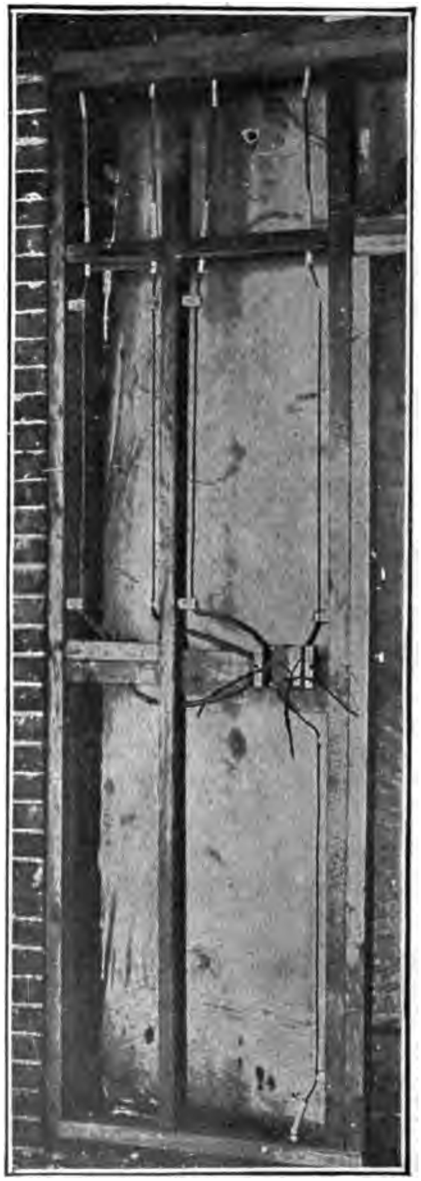


Fig. 109. Wiring in Partitions Showing Use of Porcelain Tubes

are used, metal boxes are absolutely necessary and in Fig. 108 several such boxes are shown as well as the method of mounting them on cross strips between the uprights. This illustration shows also an allowable use of flexible non-metallic tubing on wires in concealed work where it is impracticable to maintain the 5-inch separation.

Fig. 109 shows at the bottom the extra porcelain tube which should be put on each wire passing through timber at the bottom of a plastered wall to protect it from the droppings of wet plaster which will fall on it during the process of closing in the wall surface. This picture also shows very clearly the flexible tubing which must separately enclose each wire at every outlet, reaching from the last porcelain support into a switch box, or on ceiling or wall outlets, where no box is used, at least 1 inch beyond the surface. In the case of combination gas and electric fixtures the tube must extend at least flush with the outer end of the gas pipe as in Fig. 110.

When in a concealed knob and tube system, it is impracticable to place the whole of a circuit on non-combustible support of glass or porcelain, that portion of the circuit which cannot be so supported must be installed with *approved* metal conduit, or *approved* armored cable, except that if the difference of potential between the wires is not over 300 volts, and if the wires are not exposed to moisture, they may be fished if separately encased in *approved* flexible tubing, extending in continuous lengths from porcelain support to porcelain support, from porcelain support to outlet, or from outlet to outlet.

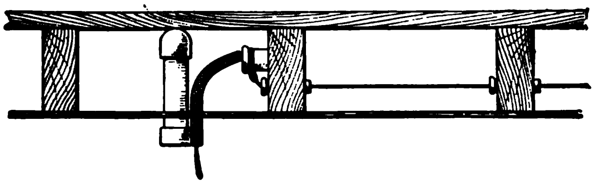


Fig. 110. Section Through Floor Showing Use of Tubing or Loom

There can, of course, be no assurance that such fished wires do not lie in close contact with gas or water pipes, or other wires, and so there is need of the protecting tubing.

In judging an installation of wires in concealed work, special attention should be paid to the wire joints. The rules allow these to be made in concealed spaces by means of soldered joints well covered with both rubber and friction tape. The wiring is usually on the so-called "tap plan," that is, taps or branches taken off wherever convenient. The necessity for good workmanship is evident as bad joints may easily set fire in dry floor and wall spaces. Fig. 111 shows such a defective joint which was found behind a lath-and-plaster partition. The joint was not taped and was hot when discovered. What is called the "loop-plan" is occasionally employed, all joints or taps being made at outlets where suitable boxes are

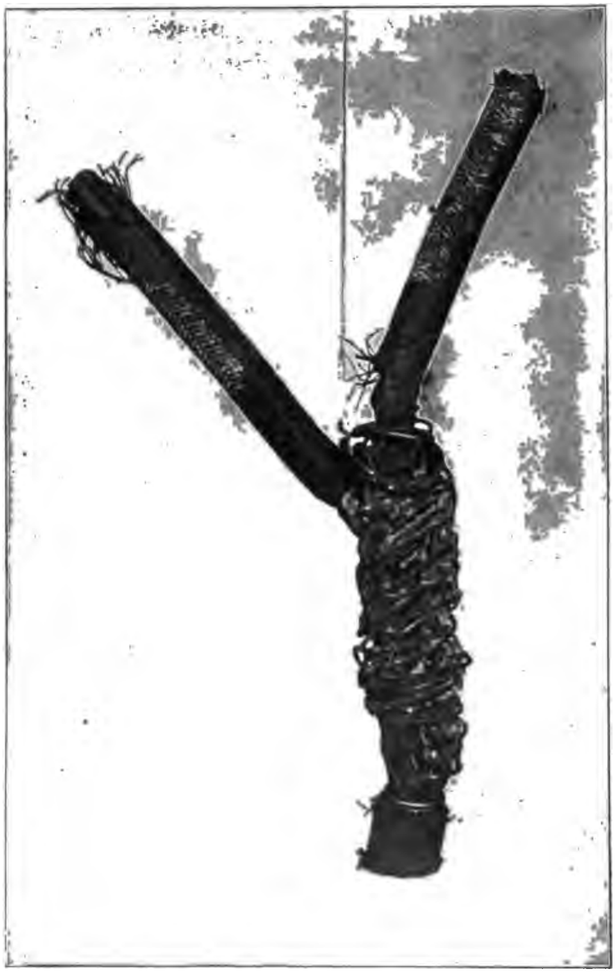
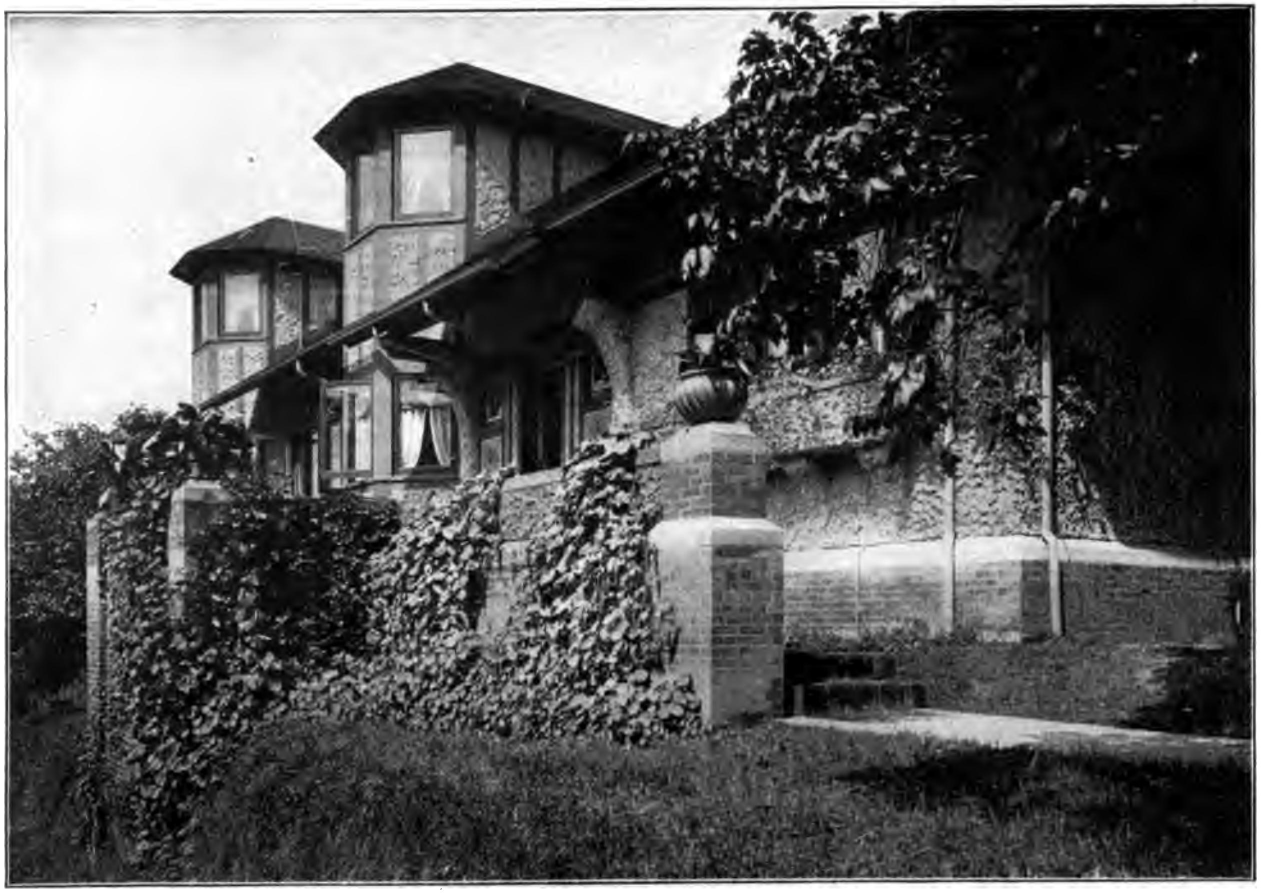


Fig. 111. Defective Joint Found in Actual Use



HOUSE AT PARKERSBURG, W. VA.

R. C. Spencer, Jr., Architect, Chicago, Ill.

Red Brick to Water Table. Rough-Cast Plaster on Metal Lath on Stud Frame above Water Table. Woodwork is Undressed. Stained Shingle Roofs.

provided. This involves the use of more wire, makes the conditions at outlets more crowded, and is perhaps not as good for concealed work under the conditions usually obtainable. Either system is permitted by the rules.

Armored Cable. Armored cable for interior wiring consists of double-braided, rubber-insulated, twin wires, covered with a spiral steel strip armor which protects the conductors from injury and is at the same time flexible. It is largely used in wiring old buildings since it can be drawn into concealed spaces without fear of injuring the conductors. It is also used for new work and is in some ways easier and cheaper than rigid conduit. Fig. 112 shows a piece of twin-conductor house cable and some of the fittings for use with it.

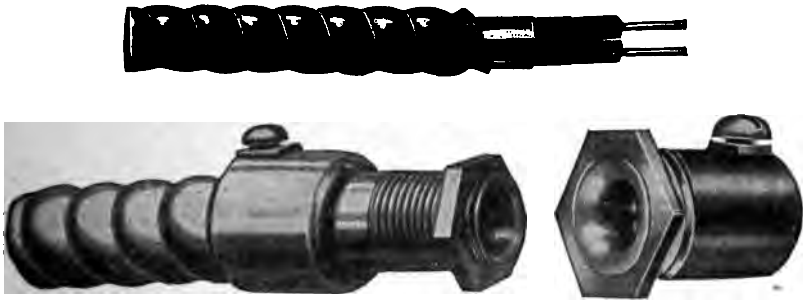


Fig. 112. Armored Cable and Fittings

With armored cable all joints must be made at outlets or in cabinets or junction boxes which are always accessible. No taps or joints are permissible except at such outlets or boxes. Great care should be taken to secure the armor very firmly to all outlet boxes in a way to give a good connection both electrically and mechanically, and the armor system must be permanently and reliably *grounded*. Where dampness may be expected there must be a lead sheath between the braided wires and the outer armor since the cable is not thoroughly moisture-proof.

Armored cable installations are superior to molding, open work, or concealed work, in that the wires are better protected. The fact that twin wire is used instead of separate conductors is at least a theoretical disadvantage, and the cable unless leaded is not absolutely waterproof.

The chief disadvantages of armored cable as compared with rigid conduit, consist in the somewhat greater difficulty of making good connections to the armor at outlets and still more in the impossibility of drawing out wires which have proved defective. However, for many places a thoroughly good job can be done with armored cable. Fig. 113 shows a characteristic piece of work of this sort.

Conduit Work. The earlier forms of conduit for interior wiring were made of paper or fiber and later of paper with a thin brass casing but these forms are now obsolete and entirely displaced by steel conduits made of either rigid pipe or flexible steel spirals. A limited use is still made of a form of conduit having a steel pipe lined with a heavy paper impregnated with some material to exclude moisture. This is, however, going out of use and almost all conduit work is now done with unlined pipe. Conduit, however, differs from ordinary commercial pipe such as is used for gas, water, or steam, in that it is carefully cleaned in the process of manufacture and then protected from rust both inside and outside by a good baked enamel or by some form of zinc coating. *Rigid conduit*, Fig. 114, gives a rather more workmanlike job than *flexible conduit*, Fig. 115, but the latter can be used in some places, especially in old buildings where

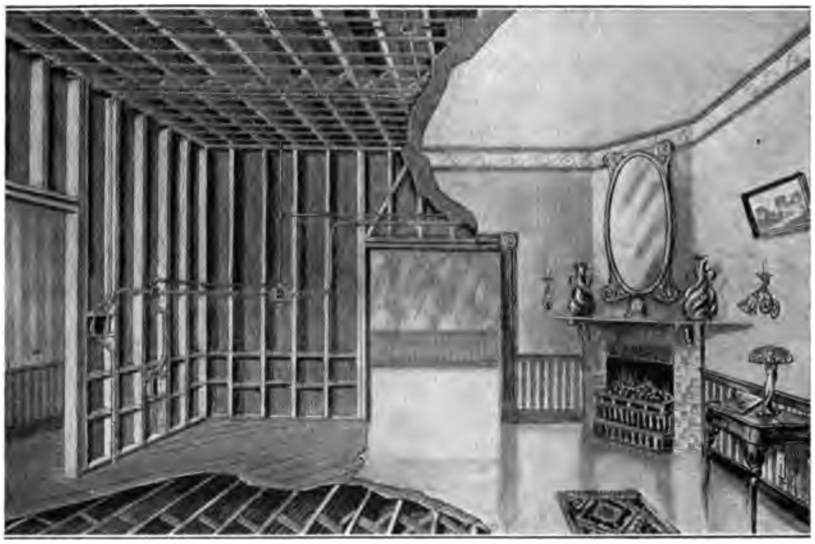


Fig. 113. Wiring Showing Use of Armored Cable

the use of rigid pipe would be impossible. If well fastened at all outlets and at all bends it affords a protection to wires second only to the rigid conduit. The complete protection afforded by conduit both of the wires from mechanical injury, and of the surrounding parts of the building from fire resulting from a burn-out of the wires, makes conduit work undoubtedly the safest form of electrical installation and one which is becoming more and more used, not only in the more expensive type of buildings but also in cheaper work as well.

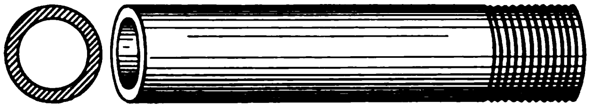


Fig. 114. Rigid Conduit

The essential principle of conduit work is to furnish a complete, strong and unbroken metal enclosure for conductors between outlets and to give to this metal-pipe system an electrical continuity and carrying capacity sufficient to serve as a safe path for any current which the failure of conductors within may impose upon it, for a time long enough to operate the fuses or circuit breakers protecting such conductors. It is also an essential characteristic of a correct conduit installation that all conductors can be *drawn in* after the entire conduit system is put into position and can at any subsequent time be *drawn out* in case any wire fails and must be replaced. These fundamental ideas will explain the reasons for most of the details prescribed in underwriters' rules for conduit work.

The construction details of steel conduit will be briefly discussed later and we consider here only methods of installing it.

There must be no breaks in the conduit system, that is, the pipe must be continuous from outlet to outlet or junction boxes. At every outlet metal boxes must be provided which the conduits must properly enter and to which they must be mechanically secured. This is usually accomplished by means of either

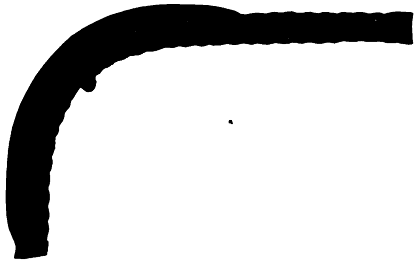


Fig. 115. Flexible Conduit

threaded lock nuts on the pipe outside the box and threaded bushings on the pipe inside the box or by threading the conduit into tapped holes in the box. With flexible conduit a special approved clamp must be used for this purpose. Fig. 116 shows a box with a rigid conduit on one side and a flexible conduit on the other side together with a few of the fittings used in connection with it. No conduit having an internal diameter less than $\frac{5}{8}$ inch is allowable since this is as small as will permit wires of required minimum size to be drawn in without injury.

All elbows and bends in the piping must be so made that the conduit will not be injured and there should not be more than the equivalent of four quarter turns from outlet to outlet, not counting bends at the outlets themselves. If more turns are required, or wherever it would be difficult to draw in the wires, additional outlets called junction- or pull-boxes should be put in to facilitate the insertion of the wires. There should be no sharp edges, burrs or other obstructions either in conduits, at couplings between lengths, or at outlets, as they are apt to injure the wire coverings. Therefore, all ends of pipe should be reamed out before they are put into the pipe couplings or into boxes, and all bushings should have smoothly rounded edges.

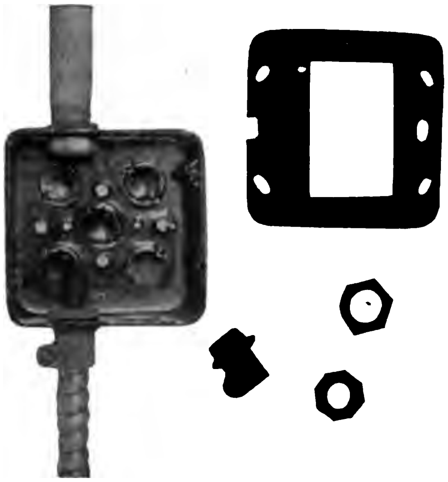


Fig. 116. Outlet Box with Connecting Conduit

The entire conduit system must be installed complete and, in fact, all the mechanical work on the building must be completed as far as possible, before any conductors are drawn into the conduits.

Pains must be taken to make all joints tight, so that there will be no bad electrical connections between parts of the metal system. It is not, of course, expected that under normal conditions the conduits will carry any current, but under some circumstances if the insulation of a wire fails, current may pass over the conduit. If the conduit is well grounded and all joints are well made a safe path to "ground" is afforded for a current large enough to blow the fuses protecting the circuit, thus cutting off the current before the pipe is overheated or burned through at the point where the bared wire has come into contact with it.

Conduits and gas pipes must be securely fastened in metal outlet boxes so as to secure good electrical connection. Where boxes used for centers of distribution do not afford good electrical connection, the conduits must be joined around them by suitable bond wires. Where sections of metal conduit are installed without being fastened to the metal structure of buildings or grounded metal piping, they must be bonded to a permanent and efficient ground connection.

It is rarely possible to perfectly insulate a conduit system throughout, and a positive ground is, therefore, required, so as to provide a definite path for leaking currents and thus prevent them from escaping through parts of a building, etc., where they might do harm.

The size of conduit which should be used for different sizes of wire or for different numbers of wires of specified size, depends upon the length of run between outlets where wires can be pulled or fed in, upon the number and the radius of bends and the thickness of the insulation on the wires. The rules, however, state that the same conduit must not contain more than four two-wire, or three three-wire circuits of the same system, except by special permission of the Inspection Department having jurisdiction, and must never contain circuits of different systems, that is, from different generators whether of the same voltage or not or whether both d. c. or a. c. or one of each.

In tall buildings special provision must be made to support the conductors in the vertical conduits to remove their weight from the connections, and the spacing of supports in such cases is prescribed as follows: No. 14 to 0 every 100 feet; No. 00 to 0000 every 80 feet; 0000 to 350,000 c. m. every 60 feet; 350,000 c. m. to 500,000 c. m. every 50 feet; 500,000 c. m. to 750,000 c. m. every 40 feet; 750,000 c. m. every 35 feet.

The following methods of supporting cables are recommended:

(1) A turn of 90 degrees in the conduit system will constitute a satisfactory support.

(2) Junction boxes may be inserted in the conduit system at the required intervals, in which insulating supports of *approved* type must be installed and secured in a satisfactory manner so as to withstand the weight of the conductors attached thereto, the boxes to be provided with proper covers.

(3) Cables may be supported in *approved* junction boxes on two or more insulating supports so placed that the conductors will be deflected at an angle of not less than 90 degrees, and carried a distance of not less than twice the diameter of the cable from its vertical position. Cables so suspended may be additionally secured to these insulators by tie wires.

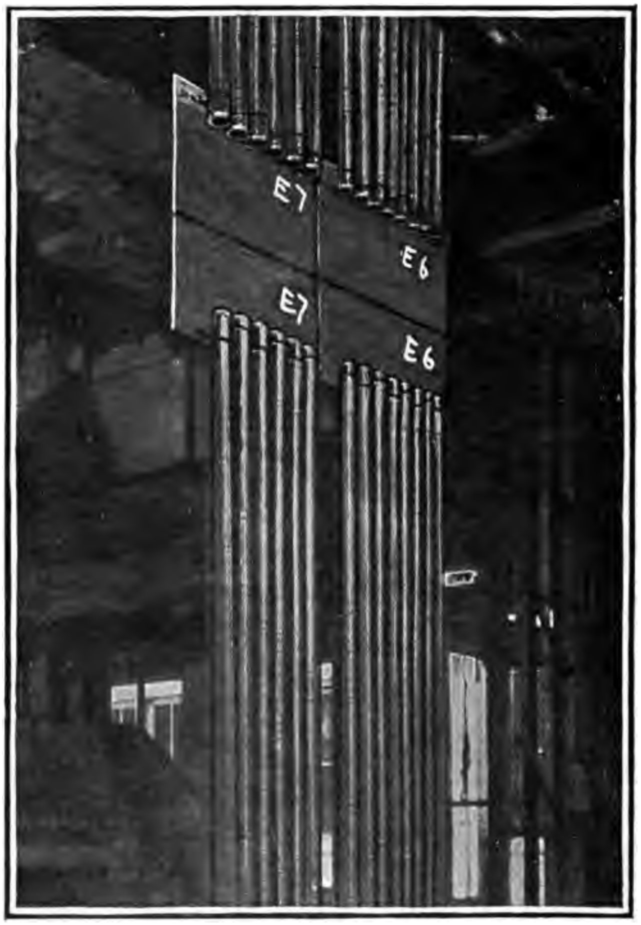


Fig. 117. Method of Supporting Conduit Risers

The second method is illustrated in Fig. 117 where a space has been left in conduit risers. The conductors will be held to the back plates by clamps and the whole will finally be enclosed in a heavy steel box which will form the connecting bond in the riser system. Fig. 118 shows one form of cable clamp used for this purpose.

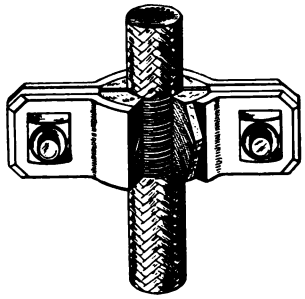


Fig. 118. Cable Clamp Used in Conduit System

Wires for conduit must be rubber-covered and have a double braid over the rubber. Twin wires are universally used for the smaller sizes, No. 14 to No. 10, and these have a braid over the rubber of each conductor and a second braid over both conductors together. For larger sizes single conductors, double braided, are used and for the largest sizes only one conductor is usually run in a pipe It should be noted, however, that for alternating-current systems the two or more wires of any one circuit must be drawn in the same pipe since otherwise there will be excessive heating of the metal pipes due to a magnetic action peculiar to alternating currents and known as "induction." Fig. 119 shows three large feeder ducts passing out of a steel service box. In this case the circuit was three-wire direct current.

The design of a conduit system of wiring for a large building may be a problem of some magnitude involving no little engineering skill and experience if the most economical, efficient, and sightly results are to be secured. A full exposition of the methods followed and the reasons for them does not fall within the scope of this book but the following general considerations are of some value in judging both the advantages of conduit work and the excellence of any given installation. In all conduit work it should be remembered that no taps or joints are permitted in conductors except at outlets, junction boxes, and cabinets, and that all these must be in accessible places. By accessible is meant accessible not only during the process of installation of the system but also after the building is completed and in use. A junction box is not "accessible" if it is necessary in order to get at it, to take up portions of floors or make openings in ceilings or side walls. This prime requisite of conduit work makes it necessary to run all conductors on the "loop" plan which means that all lines, branches, and control circuits (as to switches) will consist of a pair of wires starting at the same point at some outlet box or cabinet and running generally in the same pipe to some other outlet where the socket, switch, or other device is placed. Conduit systems may be made with the piping concealed or exposed as may be dictated by the character of the building and the finish desired.

In frame buildings where the electric installation is put in during the original construction the conduits are placed after the main framing and partitions are in position and will be arranged to pass through walls and floors with the outlet boxes and cabinets set and fastened securely at or very near the places where they will be when the building is done. In laying out such work little regard need be paid to having pipes run straight or parallel to each other so long as they are so shaped at bends and otherwise disposed as to make it easy to draw in the wires. The chief considerations are the position of outlets, the proper pipe sizes for the wires, and the proper subdivision to secure correct fusing of incandescent lamp circuits according to the rule which permits not over 660 watts on any such circuit.

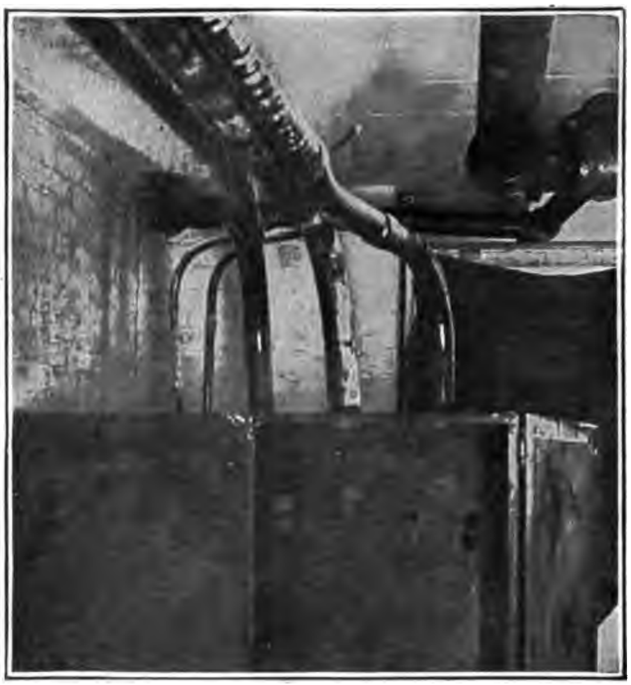


Fig. 119. Steel Service Box and Feeder Pipes

Characteristic Conduit Installation. Fig. 120 shows a characteristic layout for conduits and outlets for a small apartment

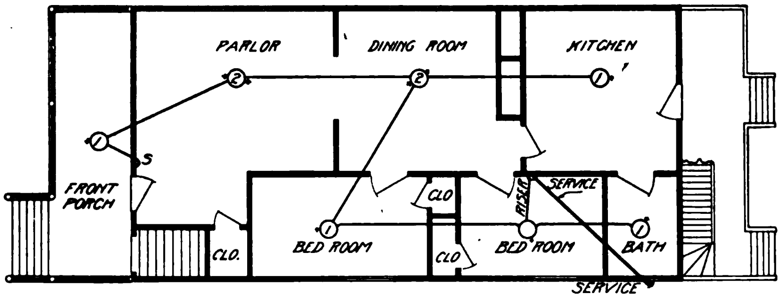


Fig. 120. Characteristic Layout for Conduits and Outlets in Small Apartment

At the point marked "riser" a main conduit rises from the "service" in the basement and on each floor has a cabinet where the supply wires for that floor are taken off and fused and where the meter may be installed. In laying out such a system of conduits or in inspecting it one should start from the service entrance cabinets from which the conduits should enter. If this cabinet contains not only the service fuses but also the sub-fuses of the branches, the several circuits should be examined to see that they are properly fused, and that they are distributed in pipes of adequate size. The several runs of conduit should then be followed throughout their entire length to see that all couplings between pipes and all attachments to outlet boxes are thoroughly tight and that both conduits and boxes are

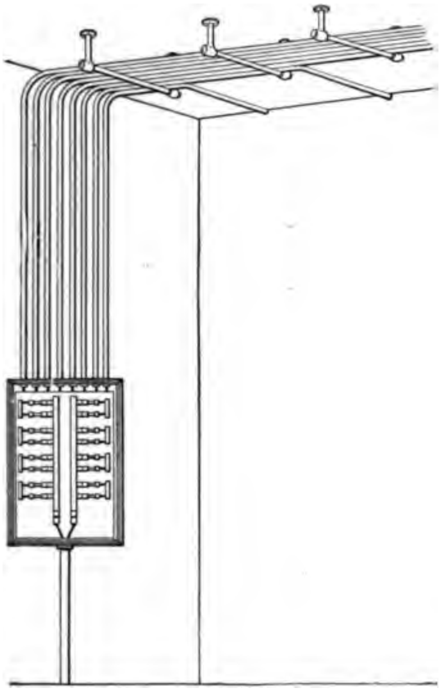


Fig. 121. Approved Ceiling Support for Conduits

fastened by straps or screws so that no strain will be put upon the screwed joints. Care should be taken to see that there are no sharp bends anywhere and that no more outlets are set in one circuit than is proper and that all are accessible. Observe whether due provision has been made for installing fuses wherever there will be a change in the size of wire. It is often cheaper and more satisfactory to continue a somewhat larger wire than is required, than to change to a smaller size and insert fuses. In no case should fuses be installed in small outlet boxes, but only in junction boxes or cabinets of ample size.

After the wires have been drawn in, observe whether it is possible to trace a given pair from outlet to outlet and if there is doubt on any point it may be necessary to demand that certain wires be drawn out for inspection. There should, of course, be absolutely no corners, Y-shaped fittings, or other devices in any place which will prevent any or all wires from being taken out and replaced at any time even after the building is completed. It is well to observe whether there are bends or traps in the piping in which water resulting from condensation or otherwise can collect. All conduit should be practically uninjured by the work done on it, all pipe ends should be threaded and reamed and the entire metal system should be firmly supported and secured so as to be free from vibration or rattle. The system must be electrically continuous throughout and must be permanently and effectively grounded.

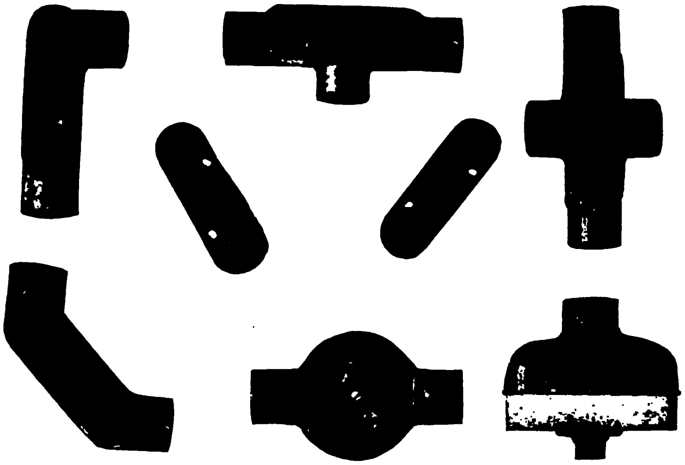


Fig. 122. Fittings Used for Exposed Conduit Work

Where conduits are run exposed, more attention should be paid to appearances. All runs should be in straight lines parallel to walls of the rooms and arranged in a symmetrical and orderly manner. Smaller sizes of conduit can usually be fastened to ceilings or walls by ordinary pipe straps, but where large conduit is used some form of pipe hanger is required and there are special patterns of a variety of designs. Where a number of conduits are run parallel the form of supports shown in Fig. 121 is excellent. With exposed conduit a variety of fittings can be used for outlets, junction boxes, and the like, which add much to the neat appearance and also provide for joints and traps as well as for mounting sockets, switches, and other small devices. Fig. 122 shows a few such fittings for exposed conduit.

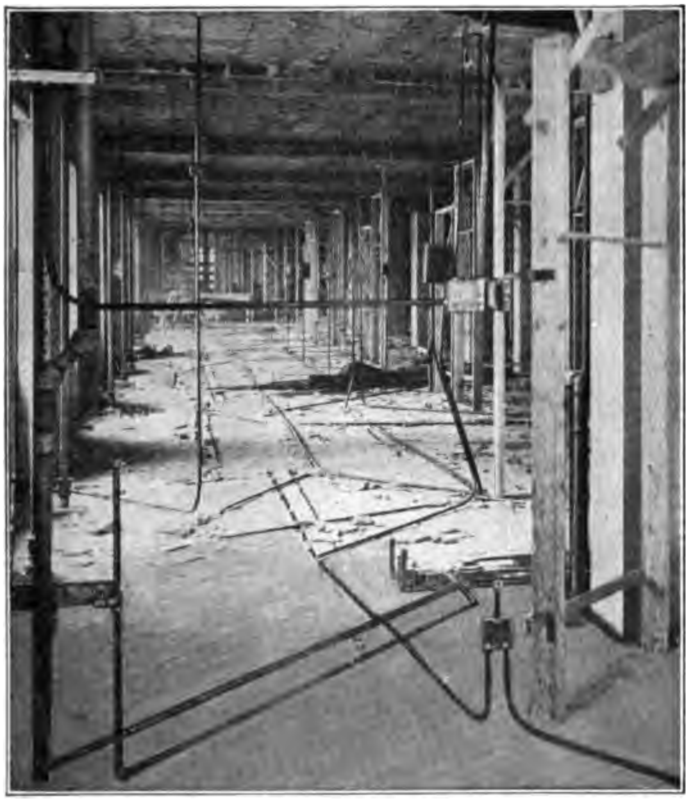


Fig. 123. Conduit Wiring Circuits Laid before Partitions and Floors are Completed

These are made with threaded nipples into which the conduit may be screwed and when so used these fittings need not be fastened to the wall or ceiling in any way, but are considered to be firmly enough held by the pipe itself. However, if boxes requiring lock nuts and screw bushings on pipes are employed they must be separately secured to the surface of wall or ceiling by screws and all cabinets of any size whatever should be so fastened. Exposed conduit work is usually employed in factories, warehouses and elsewhere if the finish of room does not require all piping to be out of sight.

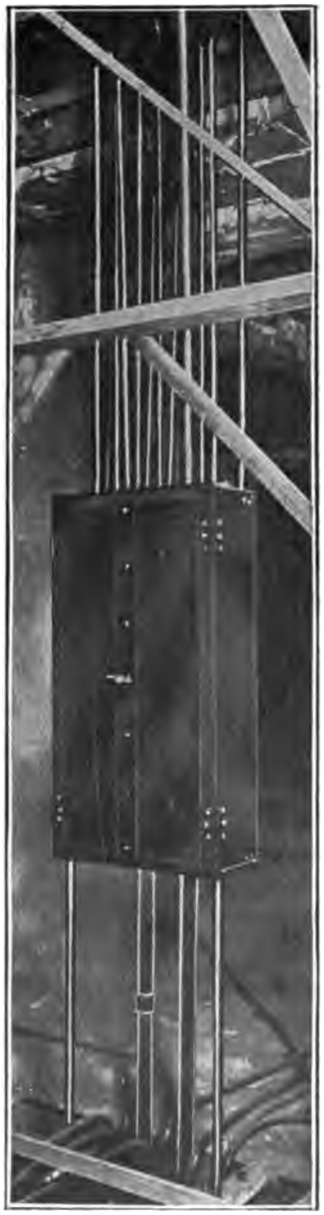


Fig. 124. Wire Distributing Cabinet

Some special problems arise in conduit work in fireproof buildings. In these types of structure the conduit work is done after the rough floor work is completed, the conduits being usually laid on the tile floors so as to be covered by the top finish of cement usually laid over the tiling. Fig. 123 shows such an installation and it will be noted that the baseboard and all side-wall outlets have been placed, before the tile partitions between the rooms, have been set. In a fireproof building it will generally be necessary to run the main risers before the floors are made and to arrange for the distributing cabinets on each floor. Fig. 124 shows a cabinet in place in the unfinished partition with two conduit risers entering it from below and the branch circuits going out from the top to various parts of the building. The cabinet in this case has been fastened by rods above and below.

In concrete buildings it is often somewhat difficult to place the conduits and the boxes so as to clear the reinforcing material and at the same time keep the metal parts well covered at all points. Special methods have to be adopted varying with the type of concrete construction employed but in all cases an effort should be made to secure proper draining of conduits. The water from the concrete is very liable to get into the conduit system at the outlets or elsewhere, and when once this occurs it is difficult to get it out. Its presence is, however, most objectionable as it tends to injure the piping by rusting and also to deteriorate seriously the insulating coverings on the wires. This is a difficulty which should be considered in locating outlets in such a building and which requires very great care to entirely overcome. It is a matter of some difficulty at times

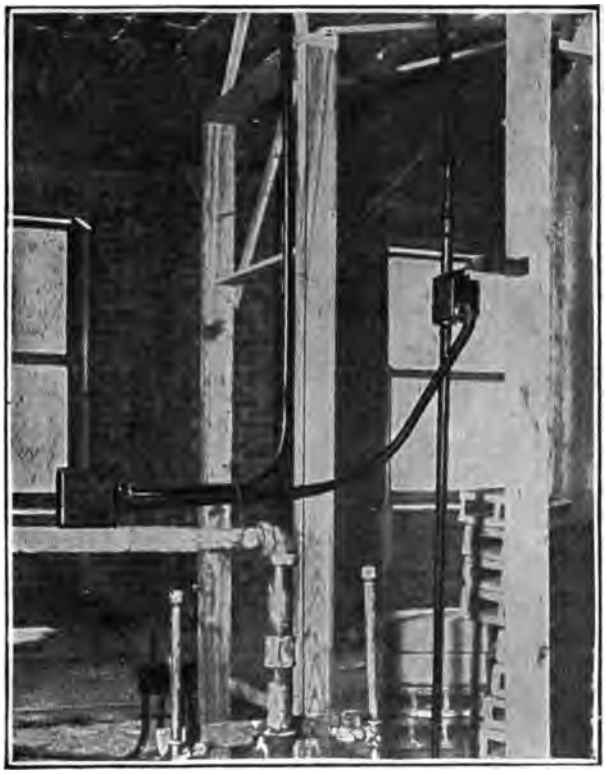


Fig. 125. Method of Placing Outlet Boxes in Tile Partitions

to secure outlet boxes on the concrete forms or in correct position where tile is to be used so as to be sure that they will be in the right position and firmly held when the building is completed. Ceiling boxes should be held by special hangers from each box up into the tile or concrete and reliance should not be placed on the conduits alone to hold them. Boxes set where tile partitions are to be subsequently erected should preferably be held by iron straps to adjacent steel work wherever this is practicable. Fig. 125 shows how this may be done.

SPECIAL INSTALLATIONS

DECORATIVE AND COMMERCIAL LIGHTING

Decorative Lighting. Decorative lighting by means of incandescent lamps is often desired either inside or outside buildings. The chief hazards of such work lie in the use of inferior materials hastily put together and poorly located and fused. The voltage should never exceed 150 volts in such work and not more than 1,320 watts of energy should ever be allowed to be dependent for protection upon a single cut-out. It is highly improper to take current for such systems from ordinary outlets which are wired for only small currents, since by so doing the wires to the outlets will be overloaded and the proper fuses for the wires will have to be replaced by others of too great capacity to furnish safe protection. The supply should be taken only from points on the circuit (as at distribution boards or panels) where the correct fusing and wiring can be provided for.

There is obviously no real distinction between *decorative* lighting and *ordinary* lighting arrangements except that the former is usually put up for temporary use only. If these temporary circuits are installed in a workmanlike manner and if good wire and good sockets are used there need be no special hazard provided the wires are not tacked up in a manner liable to injure the insulations and are not made to serve as supports for inflammable decorations of cloth or paper. Festoons of keyless weatherproof sockets well connected to standard rubber-covered wire (not flexible cord), and kept separated from all combustible stuff, do not present any great hazard but no such installation should be made without great care and should never be allowed to remain as a permanent installation unless it is fully protected and made the equivalent of standard work in every respect. The use of extra "carrier" wires for such festoons is very desirable as they remove all strain from the current-carrying wires and connections. Show windows are very frequently decorated by temporary electric displays of all sorts especially during the holiday season and such window displays are very often wired in utter disregard of all safe rules. The wires are often made to serve as supports for merchandise of very inflammable material, and where tinsel, cotton batting, and similar materials are employed, the conditions are excellent for a rapidly-spreading fire if any electric failure should occur. Incandescent lamps are often allowed to lie against inflammable materials and small motor-operated advertising or other novelties may contribute their share to the danger. The fact that an installation of this sort is "temporary" does not lessen the hazard so long as it is in operation and should not in any sense be considered as an excuse for allowing practices which are known to be dangerous. Property owners are often ignorant of the extent to which ill-advised temporary decorations jeopardize their buildings.

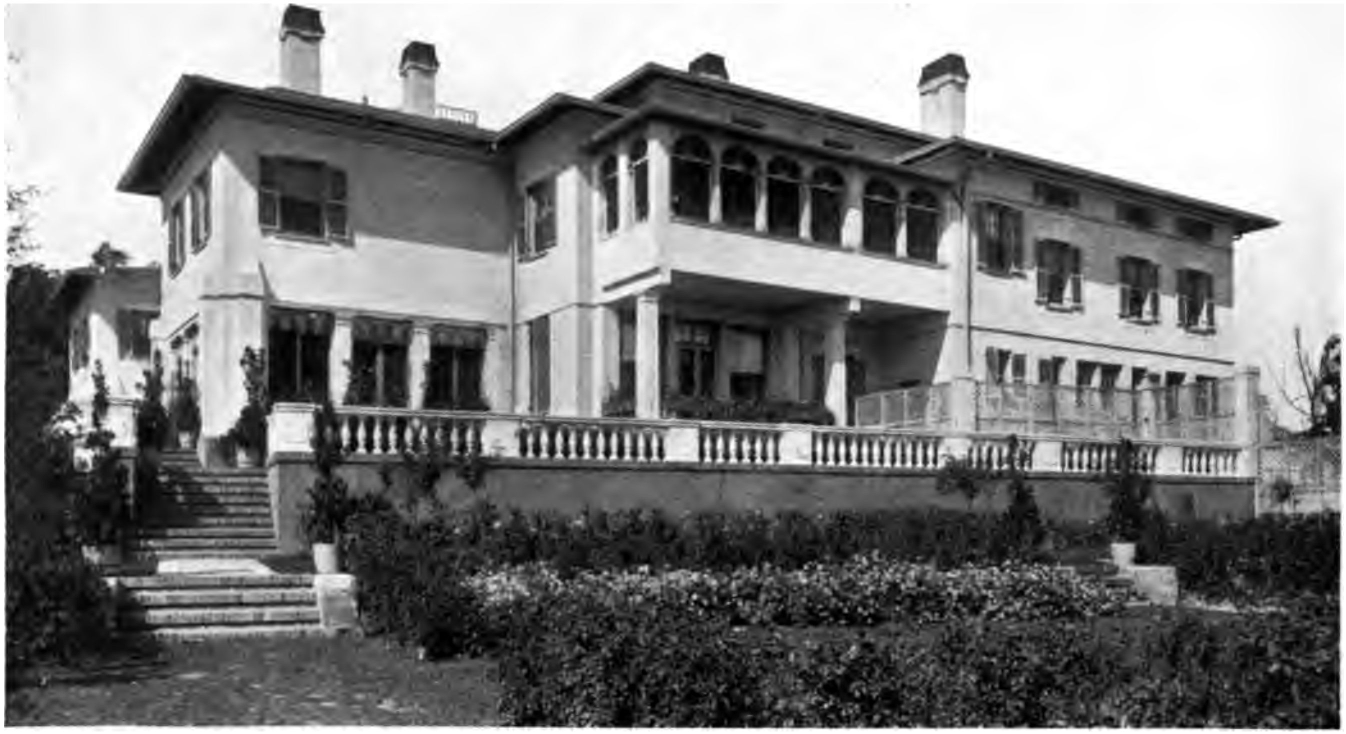
In show-window lighting, the lamps, whether temporary or permanent, should be placed either in the front or the top of the window, proper reflectors being used to throw the light upon the goods displayed. This plan almost invariably gives better results in lighting than lamps placed in sight, and scattered through the window and among the goods, and is also very much safer.

Outline Lighting. A very common form of decorative work consists of what is known as *outline lighting.* In this class of work rows of incandescent lamps are used on the exterior of buildings to outline the chief architectural features, to mark entrances, etc. Lamps and wiring used for such purposes inside buildings come under the regular rules for inside work but outside outline lighting may have special treatment. Only low potentials (under 550 volts) should be used and the wiring should be either open or trough work, or in conduit. Molding, either wood or metal, is not allowable since it does not afford protection against moisture. In open work the same spacing of wires from the surface (1 inch) and from each other (2½ inches) must be maintained as in all exposed wiring in damp places. If the use of flexible tubing is necessary, as at crosses or where regular spacing cannot be maintained, the ends of the tubing must be sealed and painted so as to exclude moisture, and for a similar reason armored cable, if used, must be of the type having a lead sheath over the conductors and under the armor.

In order to assure proper control and fusing of outline-wiring circuits they should have their own separate switch and fuses enclosed in a suitable metal cabinet which must be watertight if placed out-of-doors. Small candle-power lamps (2 to 4) are almost always used for outline wiring and may be so grouped on the circuits that not more than 1320 watts will be dependent on a single pair of fuses. This limitation of the amount of wattage to be carried by a single circuit is to prevent any trouble in a single socket causing too much arcing or burning before the fuse protecting its circuit will open. All the sockets and receptacles in outline wiring must be of the keyless porcelain type and the wires connecting them must be soldered to the lugs. With conduit work in outline wiring special attention should be given to making the entire system as water tight as possible. The receptacles set in the covers of steel outlet boxes or *conduits* should be provided with rubber gaskets, and similar rubber rings may also be used to advantage about the bases of the lamps to prevent the entrance of water into the receptacles themselves.

Electric Signs. An endless variety of electric signs are shown on the streets of cities and towns today, from the simplest illuminated panels to huge structures containing many hundreds of lamps and operated by very complicated "flashing" machines. An elaborate treatment of all types of signs cannot be given here. The large signs erected on roofs should come under the supervision of the building department of a city or under both electric and building departments. Many of these signs are hazardous because of the obstruction they offer to firemen, the large amount of power they use, and the inadequate provision made for cutting off current from them either automatically or by hand switches in accessible places. No combustible material should be permitted either in or near such signs.

It is preferable that all the wiring be in conduit but where this is impracticable, the supports and spacing of wires should be excellent and the sides of the circuits should be kept apart preferably by bunching all wires of one polarity into cables covered by waterproof and slow-burning jackets. The mass of inflammable rubber-covered



RESIDENCE OF ED S. MOORE AT LAKE FOREST, ILLINOIS
Arthur Heun, Architect, Chicago

and braided wire necessary for a large sign requires skilful arrangement to avoid a serious blaze in case of failure.

Signs of every size should be "all metal," sheet steel being not less than No. 28 U. S. gauge and frames being in all cases of ample stiffness and strength. Metal parts should be well protected by paint or enamel and the sign structure should be reasonably water tight but have drainage holes in the bottom to let out any water that may collect inside. The wires should be soldered to all receptacle terminals, should be rubber-covered, double-braided, and brought out through the sign structure either in conduit or in well spaced porcelain bushings with drip loops. In supporting the sign attention should be paid to preventing wear or abrasion of the leading-in wires by swinging of the sign. Many cities have especially elaborate rules for the placing and supporting of signs designed to reduce the possibility of their falling or of their interfering too much with the use of fire-escapes or the work of firemen in case of fire in the building.

Sign Flashers. The flashing, and other very elaborate effects of electric signs, are accomplished by the use of what is known as sign-machines or flashers, Fig. 126, which consist essentially of motor-driven drum switches often of great size and complexity. These machines are hazardous chiefly from their use of many necessarily rather frail single-pole brush switches with large numbers of connecting wires leading to them and from the fact that being essentially automatic, such machines are liable to be neglected and poorly maintained. The location of a sign machine should be such as to remove it from the chance of accidental injury or tampering, to permit the direct and well arranged running of circuits to it, and to render it accessible for cleaning, adjusting, and inspecting at all times. A flasher should never be installed in a closet or other concealed space. If it is impracticable to mount it outside the building near the sign, as is preferable, a location should be chosen that

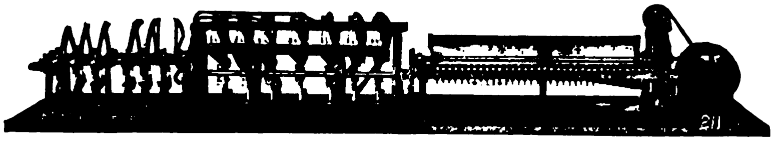


Fig. 126. Sign Flasher for Displaying Electric Signs

will reduce as far as possible the amount of wiring required. A platform or shelf over a doorway and just inside the building is often the best place available. A heavy metal cover must be provided but this should be removable so as to permit adjustment of all operating parts within.

THEATER WIRING

General Specifications. The electric equipment of theaters is of great importance both because of the large value of these properties and also because of the life hazard involved in any public building in which large numbers of people assemble. The electric equipment of a modern theater of the first class is generally very elaborate, involving as it does not only the brilliant illumination of large rooms, the stage, and many smaller apartments, but also the power equipment for handling curtains, scenery, and other paraphernalia and the numerous devices of special character for producing stage effects. In the meaning of the Code a theater is defined as a building or part of a building in which it is designed to make a presentation of dramatic, operatic or other performances or shows for the entertainment of spectators, which is capable of seating at least 400 persons, and which has a stage for such performances that can be used for scenery and other appliances. All theater wiring not specifically covered by special rules should conform to standard rules and requirements for work of its class. The special rules naturally divide into those which concern the protection of life chiefly and those which concern primarily the fire hazard, though, of course, the latter have a direct bearing on the life hazard also, since even a relatively small fire in a theater may produce a panic resulting in injury to many persons.

For the purpose of insuring the most reliable maintenance of proper lighting and consequent safety and freedom from panic in the audience, the underwriters' rules suggest that where the source of electric supply is outside the building there must be at least two separate and distinct services where practicable, fed from separate street mains, one service to be of sufficient capacity to supply current for the entire equipment of the theater, while the other service must be at least of sufficient capacity to supply current for all emergency lights. By "emergency lights" are meant exit lights and all lights in lobbies, stairways, corridors, and other portions of the theater to which the public have access which are kept normally lighted during the performance. Where source of supply is an isolated plant within the same building, an auxiliary service of at least sufficient capacity to supply all emergency lights must be installed from some outside source, or a suitable storage battery within the premises may be considered the equivalent of such service.

The principal hazards in a theater result from the stage equipment since it is there rather than in the auditorium that large currents are used; many conductors are required, and all sorts of special devices are employed often in close proximity to combustible material such as scenery. Furthermore, the constant changes, additions and special requirements for different productions result in subjecting the electric equipment to exceptionally hard wear and tear on theater stages so that proper upkeep can be secured only by the use of the most approved materials and methods and constant re-inspections. All permanent electric work on the stage side of the proscenium arch must be in conduit or armored cable except in border lights and on the stage switchboards.

All of the stage circuits, footlights, borders, arc lamps, and usually all house lighting are controlled from a switchboard located on the stage at one side of the proscenium arch. This results in a very large number of cables and wires being concentrated at this board and calls for very careful planning if anything like safe and orderly arrangement is to be secured. The space available is often small and circuits are, therefore, liable to be unduly crowded and confused. The design of a large stage switchboard calls for no little engineering skill, which is too often noticeable chiefly from its entire absence especially in older houses. The space back of the board should be of ample size, readily accessible but entirely enclosed by absolutely fireproof walls and doors and preferably directly ventilated to the outside by a special brick chimney or large flue. All circuits should be controlled by substantial knife switches and fused by standard enclosed cut-outs in accessible places where their operation will not in any way be liable to set fire to the wire insulations. It is very desirable that all wires on the back of the board be covered with asbestos jackets and be well spaced.

Dimmers. The *dimmers* or special rheostats for gradually reducing the intensity of incandescent lamps either in the auditorium or on the stage constitute often a very large installation of heat-developing apparatus which should be carefully located on iron brackets or on open galleries absolutely separated from any possible contact with burnable stuff. Fig. 127 shows a bank of dimmers.

Footlights and Borders. Among the more important fixed-appliances are the *footlights, border and strip lights,* and the *stage-floor pockets.* The footlights should be installed either in conduit or on special steel boxes which entirely enclose the lamp receptacles. Border lights must be substantially made of heavy sheet metal (at least No. 20 metal gauge) and must be wired with slow-burning wire because they necessarily get very hot from the lamps they contain.

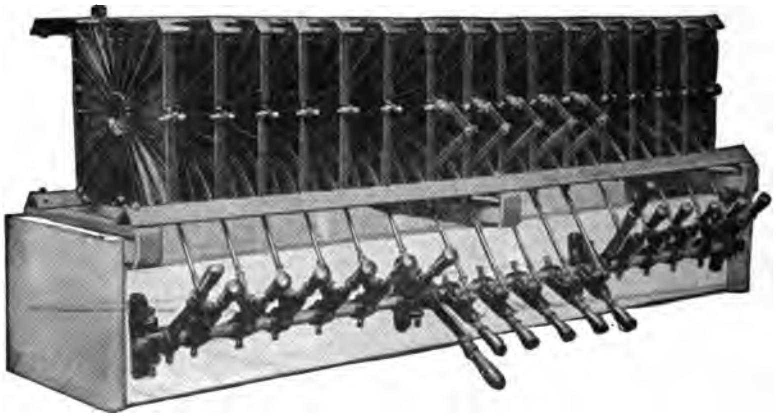


Fig. 127. Bank of Theater Dimmers

Footlights, on the other hand, do not get so hot and their location makes them susceptible to moisture during the cleaning or washing of the floor of the stage. They should, therefore, be wired with rubber-covered wire.

Border lights must be raised and lowered and, therefore, current must be carried to them by means of cables composed of stranded rubber-covered wires. Such cables should be in rigid conduit to the point where the cable leaves for the border and at this point a suitable junction box should be provided. The method of bringing the cable from this box and also of leading it into the border structure should receive special attention to prevent undue strain being brought to bear upon it at these connections. The cable should be of the

special type designed for this service. Figs. 128 and 129 show sections of footlights and borders ready for installation on a stage.

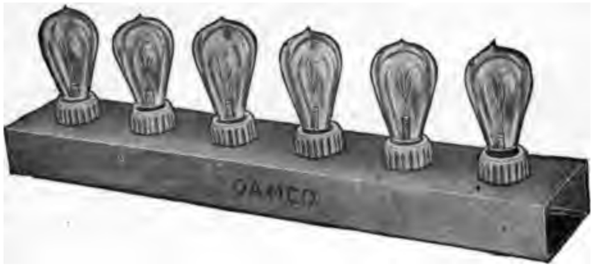


Fig. 128. Section of Theater Footlights

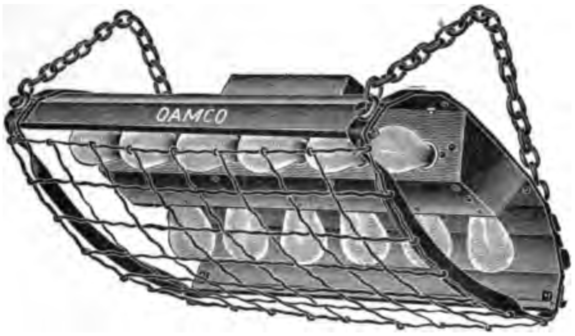


Fig. 129. Section of Theater Borders

Stage Pockets. Stage pockets (see Fig. 130) are iron boxes, having trap doors flush with the stage floor and containing receptacles for special plugs and cables by means of which arc lamps, flood lamps, and other temporary and portable devices may be connected. The circuits should have a capacity of at least 35 amperes for arc lamps or 15 amperes for incandescent lamps, wired to the full capacity and controlled from the stage board. They should contain no fuses and should be so constructed that accumulations of dust or rubbish in them cannot interfere with their safe use or be liable to cause

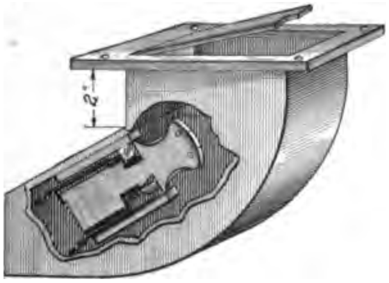


Fig. 130. Stage Pocket

a fire from any arc resulting from withdrawing the plug. These pockets may be for one or several plugs.

Portable equipments for use on theater stages include, in addition to special devices of all sorts—arc lamps, bunch lamps, strip lights, pin plug connectors, and portable plugging boxes. Fig. 131 shows a poor form of stage arc lamp of the type supposed to have caused the Iroquois theater fire in Chicago, while Fig. 132 shows a modern approved form. These should be of approved pattern, made of non-combustible materials only and fitted with standard stage cable the specifications for which are as follows: To consist of not more than three flexible copper conductors each of capacity

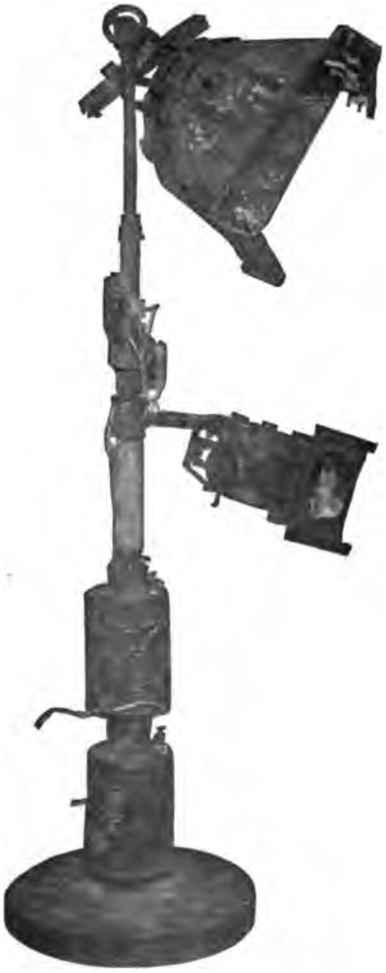


Fig. 131. Non-Approved Form of Stage Arc Lamp

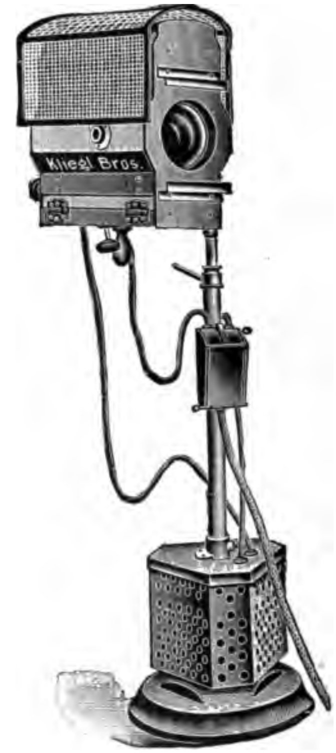


Fig. 132. Approved Form of Stage Arc Lamp

not exceeding No. 4 B. & S. gauge, built up of wires not smaller than No. 26 B. & S. gauge; each conductor to be covered with a cotton wind and with rubber insulation of thickness equivalent to standard rubber-covered wire and a saturated braid; the conductors to be twisted together with a filler (jute or a similar material) to make the cable round and to act as a cushion; the whole to be covered with two weatherproof braids. Such a cable will withstand considerable hard usage and has sufficient mechanical strength to endure the severe conditions of this service.

Special Lighting Circuits and Stage Effects. The proper installation of all of the stage devices just mentioned is,such an important feature of the safety of the theater that special rules are established for portable conductors, for lights on scenery, for festoons, and for the many special effects, such as lightning, etc.

Requirements for Stage Auditoriums. The special requirements for the lighting of stage auditoriums are as follows: All wiring must be in either conduit, metal moldings, or armored cable; all fuses must be in enclosed cabinets; exit lights must not have more than one set of fuses between them and the main service fuses, and together with all hall and corridor lights, must be supplied independently of the stage lighting and be controlled only from the lobby or front of the house. All of these requirements are made to insure adequate lighting for the audience in case of a fire, to render the exit and corridor lights independent of any accident to circuits resulting from a stage fire, and to insure a certain amount of illumination at all times in order to permit firemen to work to advantage in case of a fire in the auditorium or corridors leading thereto.

MOVING PICTURE THEATERS AND MACHINES

Interior Equipment. The very large number of moving-picture theaters which have come into use in the past few years has introduced a special hazard of considerable extent and a large number of disastrous fires in such installations have been recorded. See Fig. 133. These theaters have often been established in rooms originally intended for stores and their equipment has been of the poorest character. This condition is now somewhat improved as the danger has become more generally recognized and has been made the subject of special legislation both by insurance interests and by municipal and town ordinances.

Causes of Danger. The lighting of such theaters comes under the ordinary rules for electrical work but the peculiar danger lies in the use of the arc lamp projection machines with the highly inflammable "films" on which the pictures are printed. These films

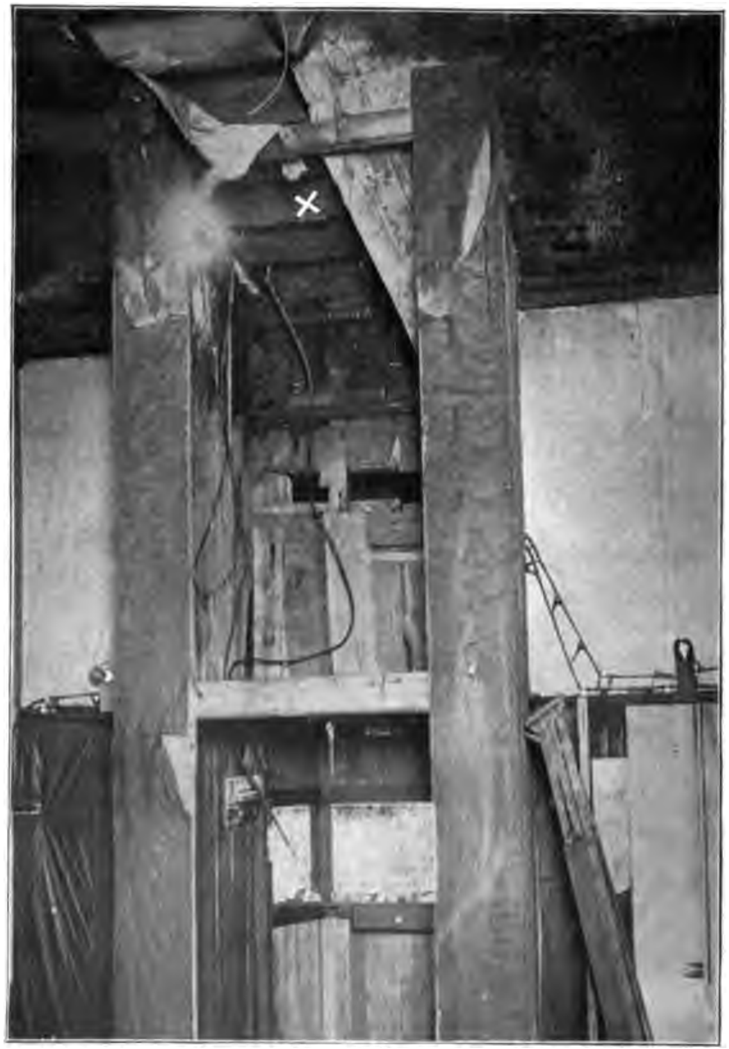


Fig. 133. Showing Fire in Moving Picture Lantern Housing Due to Inadequate Precautions

are of cellulose coated with a chemical which burns with great intensity and rapidity and with an almost explosive force. A burning film cannot be extinguished easily and evolves an enormous amount of heat and a dense and suffocating smoke. In displaying the moving pictures the film (usually 500 to 1,500 feet in length) is caused to pass rapidly in front of a special arc lamp taking from 25 to 50 amperes at 110 volts, the light and also the heat of the arc being concentrated on a small area of the film about as large as a postage stamp by means of lenses set in the head of the machine. While the machine is in normal operation, the ribbon of film is moved so rapidly that no portion of it has time to become heated. If, however, for any cause, the advance of the film is checked so that a portion of it remains for even a few seconds exposed to the concentrated heat of the arc, it is at once ignited and the flame spreads to the adjacent parts of the film and the whole reel is liable to burn up with a very intense fire which may endanger the life of the operator and create a serious fire hazard to the building. The film may also be ignited by coming into contact with the hot lamp housing or with the resistance box which it is usually necessary to use in the arc lamp circuit to regulate the current.

The arc lamp and rheostats should be constructed similarly to arc lamps and rheostats used on theater stages. Tight metal boxes made without solder must be used both to hold the reel from which the film is unwound in order to expose to view, and also to receive the film after it has passed through the machine head, and the openings in these boxes must be as small as possible, being regulated by rollers between which the film may pass or by shutters which can be instantly closed. The handle or crank used in operating the machine must be secured to the spindle or shaft, so that there will be no liability of its coming off and allowing the film to stop in front of the lamp. A shutter must be arranged in front of the condenser, so as to be readily closed. Extra films must be kept in a tight metal box. Machine may be driven by hand or by motor, but in the latter case the machine must be expressly designed and approved for such operation and must be in charge of a skilled operator. Special permission to use motor-driven machines is also required. Hand-driven machines must not be converted into motor-driven machines by the addition of an ordinary motor since some special and additional protective features are required in motor-driven machines, chiefly because with them the operator is able to run the machine with less constant attention. It is very essential that the film and the entire equipment receive the constant attention of the operator. The picture machine must be placed in an enclosure or house made of suitable fireproof material, thoroughly ventilated, and large enough for the operator to walk freely around the machine. All openings into this booth must be arranged so as to be entirely closed by doors or shutters constructed of the same or equally good fire-resisting material as the booth itself. Doors or covers must be held normally closed by spring hinges or equivalent devices.

The construction, location, and wiring of this booth are the chief considerations in the equipment of a moving-picture theater and no pains should be spared to obtain the highest possible degree of security in its construction, equipment, and maintenance.

CAR WIRING

The electric wiring of cars requires some special rules which make certain exceptions to the general rules on the one hand and which make some special extra requirements on the other hand. These special rules have to do chiefly with the protection of car bodies and woodwork over all the electrical apparatus such as motors, resistances, contactors, and the like, and over such of the conductors as are not run in conduit. Other somewhat special requirements apply to wires, cables, and methods of making joints and connections in them, to the location and type of fuses and circuit breakers to be used, to special forms of conduit and wood molding, and to details of the lighting, heating, and air-pump circuits. Very carefully detailed requirements have been worked out for the main motor circuits and for the devices used in connection with them. As all of these requirements are of a very special character, the underwriters' rules in this connection should be studied in detail by those directly interested in car wiring.

Car houses or barns present some hazards which can be reduced by the observance of a few special rules which are determined chiefly by the fact that the railway circuit is normally grounded and thus requires somewhat different treatment from the ordinary underground light or power circuits.

LIGHTING AND POWER FROM RAILWAY WIRES

It should be especially noted that under no circumstances is it proper to take lighting or power circuits from trolley or third-rail railway circuits with a ground return. This, of course, does not and cannot apply to the electric railway cars, car houses, power, passenger and freight houses connected with the operation of electric railways in which the use of such circuits is obviously necessary and which can be specially guarded and supervised. For all other factories or buildings of all sorts, power from grounded railway circuits is forbidden because of the danger of introducing into a building a circuit which has so much capacity back of it and which is thoroughly connected with the earth on one side. The inevitable fluctuation in voltage would also frequently require overfusing of the lighting circuits to prevent blowing fuses under normal conditions.

HIGH- AND EXTRA HIGH-POTENTIAL SYSTEMS

Classification. Under low, constant-potential systems are included all such as have voltages not over 550 volts but it should be noted that this distinction is an arbitrary one adopted for the classification of the rules on electrical work in relation to the fire hazard and is not made in just this way in classifying power-transmission lines and commercial systems from other viewpoints. In the underwriters' rules any circuit attached to any machine, or combination of machines, which develops a difference of potential, between any two wires, of over 550 volts and less than 3,500 volts, shall be considered as a high-potential circuit and as coming under that class, unless an approved transforming device is used, which cuts the difference of potential down to 550 volts or less. Similarly if the difference of potential between any two wires is over 3,500 volts the circuit is classed as an extra high-potential circuit unless an approved transforming device is used. This means that where the power is brought to a transformer on primary lines of not over 3,500 volts and the secondary lines are not over 550 volts, the secondary system of light or power is considered a low-potential system, but if the primary wires of 550 to 3,500 volts are direct to the power-consuming devices, as motors, without the outside transformer, the system is considered a high-potential system. If the primary lines are over 3,500 volts, the secondary lines beyond the transformers are classed as high-potential and where no transformer is employed the circuit is extra high-potential.

High- and extra high-potential systems are, of course, usually alternating-current circuits since only alternating current is ordinarily used for over 600 volts. There are, however, a number of railway installations in the United States operating at 1,200 volts direct current and this type of power distribution is becoming somewhat common. A 1,200-volt circuit is, of course, classed as high-potential. Use is made of high-potential circuits for both light and power purposes and its advantages over low voltages lie in the smaller sized copper that can be used to transmit a given amount of power over a certain distance with a specified percentage of loss due to the line wires.

Requirements for Safety. For lighting, 2,200- to 2,500-volt circuits are used to transmit the power from the generating station to standard transformers at or near buildings where the light is used and these transformers step down the voltage either to 110 or 220 volts or to a three-wire 110- to 220-volt system on the secondary side for the lamps. A very few cities and towns employ a 220- to 440-volt three-wire secondary system but this is not usual or desirable in general, as most fittings, fuses, etc., are designed for not over 250 volts.

Motors designed for alternating current may, of course, be operated on these secondaries and such secondary circuits whether for light or power are simply low-potential circuits provided the higher voltage lines end at transformers suitably installed outside the buildings or as near as possible to the point where the primary wires enter the buildings. The outside location is much to be preferred.

When circuits having high-potential transformers are located inside of buildings they should be placed in an enclosure made of fire-resisting material such as brick, tile, or concrete. The enclosure should be used for nothing but the transformers and should be kept locked. Fig. 134 shows such an enclosure or vault for transformers. It is a good plan to arrange the transformer room or enclosure so that it can be entered only from outdoors, since then, even if the door should happen to be open at the time of a fire in this room, it is probable that no especial harm would be done. Moreover, the fire could doubtless be better handled from the outside. The transformers must be thoroughly insulated from the ground, or permanently and effectually grounded, and the enclosure in which they are placed must be practically air-tight, except that it must be thoroughly ventilated to the outdoor air, if possible through a chimney or flue. There should be at least six inches of air space on all sides of the transformer. This rule will permit of either the insulating or grounding of transformer cases as seems most advisable under the conditions, but will require that with either arrangement the work

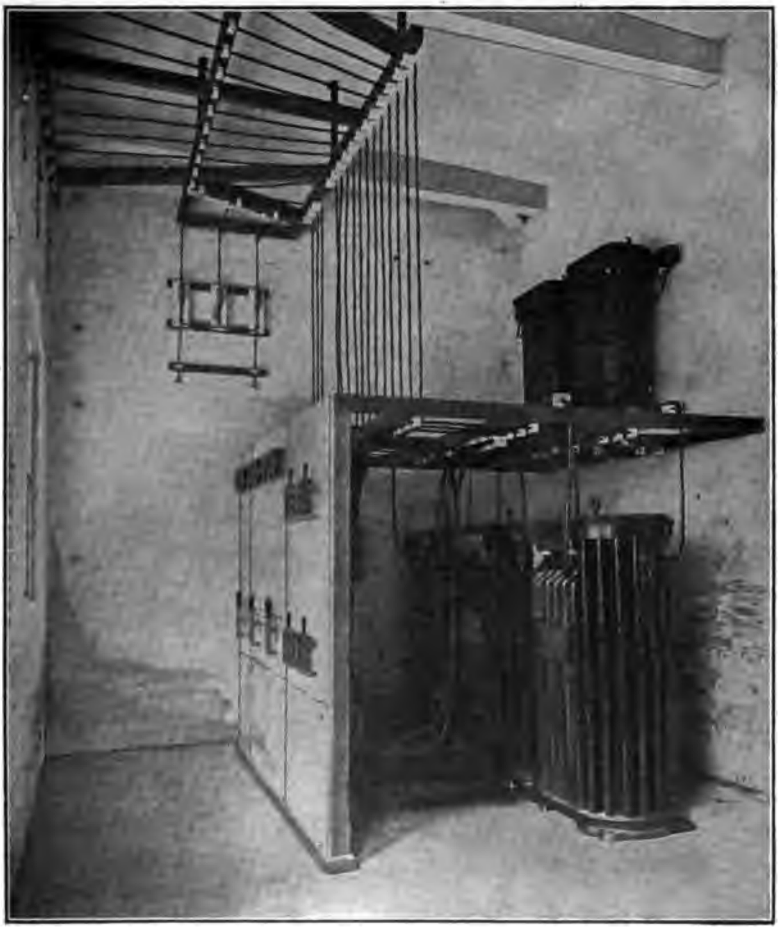


Fig. 134.[*] Approved Method of Protecting Transformers in a Vault

be well done, and that unless good insulation be provided the cases be definitely grounded. The object of an air-tight enclosure is to prevent smoke from escaping or fire from spreading, in case the transformer coils should become overheated from an overload or should be ignited by a break-down in the insulation between the primary and secondary coils. This is especially important with oil-cooled transformers in which the danger from an oil-fire is added to the usual electrical hazards involved.

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[*] *Courtesy Inspection Department, Associated Factory Mutual Fire Insurance Companies, Boston, Mass.*

Wherever high-potential circuits are brought into a building only rubber-covered wire should be used and special care should be taken with the wire supports to protect the wires from mechanical injury since a failure resulting in an arc is very dangerous at this high voltage. Substantial boxing about wires on side walls and running boards where circuits cross floor timbers are very necessary, as, in fact, are all the precautions and rules for good wiring and good workmanship throughout. A very large number of motors are now used taking 2,200 to 2,500 volts at the motor terminals. Such power installations can be made reasonably safe by careful planning of the circuits and by excellence of installation and upkeep of all wiring and connected apparatus. No multiple-series or series-multiple system of lighting is allowed on high potential circuits.

Extra high-potential circuits are not allowed either in or over buildings except power stations and substations. Where extra high-potential primary circuits (over 3,500 volts) supply transformers the secondary wiring must be installed as high-potential circuits (550 to 3,500 volts) unless the primaries are installed in complete compliance with the rules governing outside work on constant-potential pole lines over 5,000 volts or are wholly underground within city, town, and village limits.

In concluding the consideration of these higher voltage circuits, it is proper to refer again to the fact that the higher the voltage employed the greater the need of care in installation, upkeep, and operation since the results of accidental arcs are more serious.

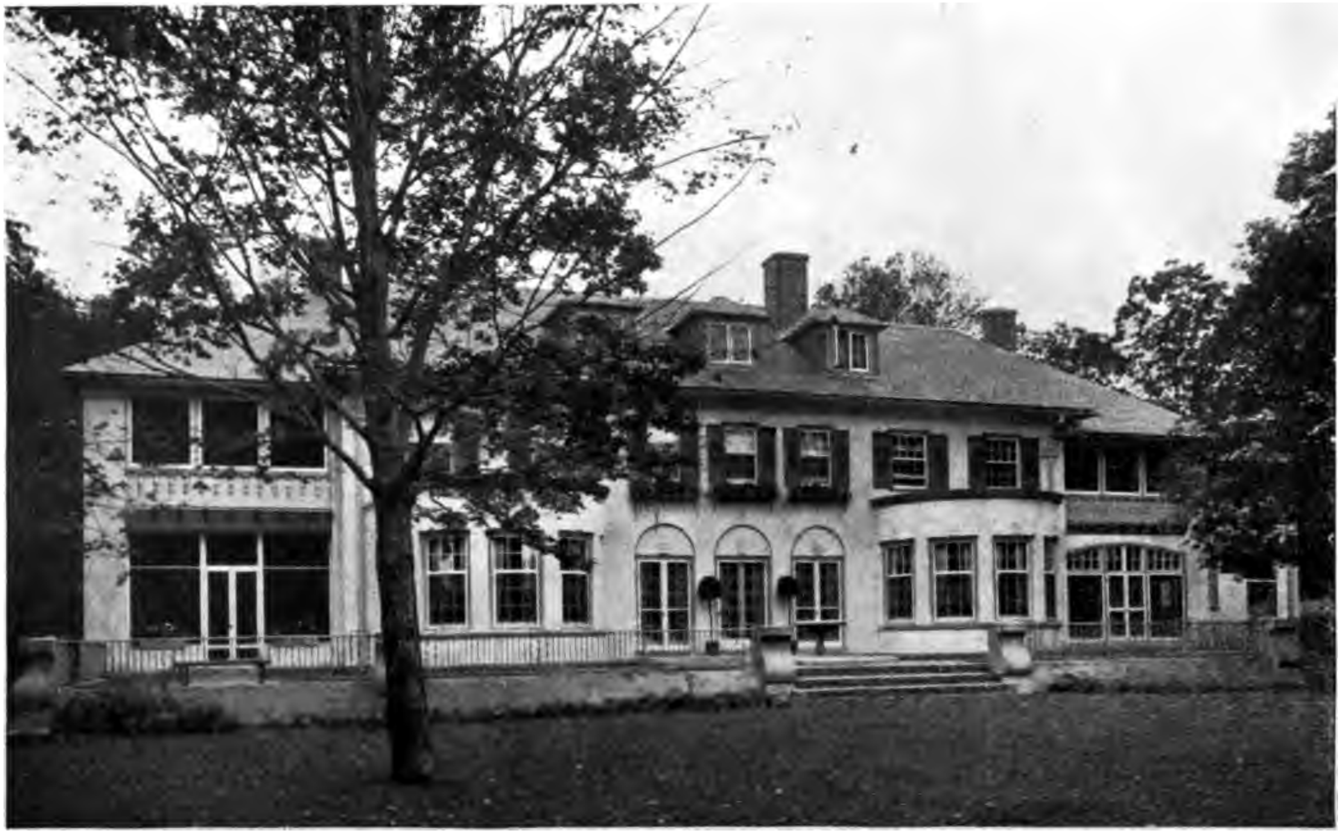
SIGNALING SYSTEMS

Wiring Requirements. The wiring and other devices in the great variety of signal systems now employed in buildings, present as a general rule no hazard except their liability to become crossed either outside or inside buildings with electric light, heat, or power circuits. Such signal systems include telephone, telegraph, district messenger and call bell, fire and burglar alarm, and all similar appliances and circuits. It is seldom that the wires of any of these systems are installed in buildings with the same care as are those for lighting or power, and the insulations employed on signal wires are very generally far inferior to those specified for light and power circuits. Furthermore, since signal systems are usually operated from either primary or secondary (storage) batteries of low voltage and limited current capacity, they may be and commonly are installed with little attention to separation of the wires, either from each other, or from the surfaces, walls, and floors to which they are attached. It follows, therefore, that all care should be taken to prevent light and power wires carrying currents of large capacity and relatively high voltages from coming in contact with signal wires since in such event dangerous fires might very readily be caused. The same advantages in having wires underground instead of being placed on poles apply to signal as well as to light and power circuits, but the two classes should never occupy the same underground duct, manhole, or handhole even when cables are used, since in the mechanical work or repairs on the lines an injury resulting in a cross between the systems might cause a dangerous current from the higher voltage lines, to outer buildings, over the weakly insulated and poorly protected signal wires. The liability of accidental crossing of overhead signaling circuits with electric light and power circuits may be guarded against to a considerable extent by endeavoring to keep the two classes of circuits on different sides of the same street. The Code prescribes that signal wires on pole lines also carrying electric light or power wires shall generally be placed on the lower cross-arms. This arrangement is not, however, favored by many engineers or by all municipal authorities, who prefer that signal wires be put on the top arms or on extensions above the tops of the poles. The arguments in favor of putting the signal wires lowest on the poles are that they are by many judged to be more liable to break and fall, especially when loaded with sleet, because of their lesser size and strength; also in case of city fire alarm circuits which are, of course, very important, the lower position enables linemen making repairs to get at the fire-alarm wires without passing up through the light and power wires which may be charged with dangerous voltages.

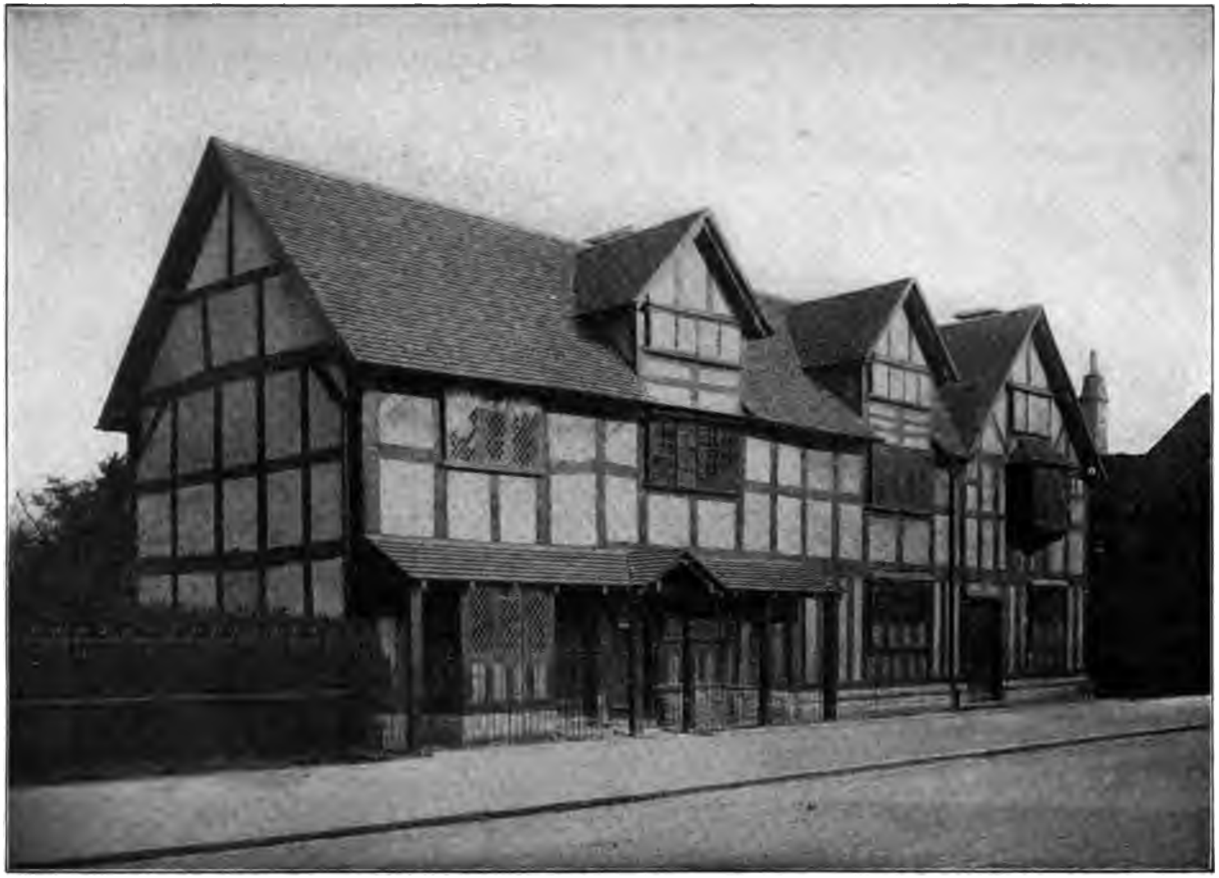
The arguments in favor of putting signal wires at the top are—they are small and, therefore, collect less ice or sleet and so are less liable to break; the light and power wires are often better insulated and a signal wire breaking is less liable to make a real live contact with them; the fall of a heavy power cable may wreck all of the signal wires if the latter are below; in the case of city fire-alarm circuits the upper location removes them from misuse and injury when wiremen are working on the other lines. However, it may be said that there is no *general agreement* either in theory or practice on this subject.

Single wires of signal circuits on the outside of buildings should have rubber insulation and where attached to frame buildings should be secured to glass or porcelain insulators or knobs. Only copper wire should be used for the span from the last pole to the building and the wires should pass through outside walls through insulating bushings and have drip loops the same as electric light wires. Inside of buildings neat arrangement and secure fastening of all wires is essential to keep them properly placed and no signal wire should come nearer than three inches to any light or power wire, unless separated therefrom by some continuous and firmly fixed non-conductor creating a permanent separation, this non-conductor to be in addition to the regular insulation on the wire as the wires would ordinarily be insulated, but the kind of insulation is not specified, as the protector described below is relied upon to stop all dangerous currents. Porcelain tubing, approved flexible tubing, or rigid conduit may be used for encasing wires where required as above. Wires where bunched together in a vertical run within any building should have a fire-resisting covering sufficient to prevent them from carrying fire from floor to floor unless they are run either in non-combustible tubing or in a fireproof shaft, which shaft should be provided with fire stops at each floor.

Signaling wires and electric light or power wires may be run in the same shaft, provided that one of these classes of wires is run in non-combustible tubing, otherwise the two classes of wires should be separated from each other by at least two inches. In no case should signaling wires be run in the same tube with light or power wires.



RESIDENCE OF DONALD R. McLENNAN AT LAKE FOREST, ILLINOIS
Howard Shaw, Architect, Chicago



SHAKESPEARE'S HOUSE AT STRATFORD-ON-AVON
Here Shakespeare was Born, April 23, 1564. Building Restored in 1857.

Protecting Devices. In signal installations where the current-carrying parts of the apparatus installed are capable of carrying indefinitely without overheating a current of ten amperes (as in some telegraph or special systems) the inside wires should be of copper at least as large as No. 16 B. & S. gauge and must have the same insulation and be supported the same as electric light or power wires for 600 volts. At the entrance to the building each wire should be protected by a 10-ampere 600-volt fuse. Such signal circuits as the above are much less common than those not suited for a 10-ampere current. Telephone, district messenger, private watchmen's time recorders, burglar alarms, and fire-alarm circuits, are never capable of carrying 10 amperes continuously and for these a special "protector" is required located as close as possible to the entrance of the building. The purpose of this protector is to prevent any foreign current or any lightning discharge from entering the building over the signal wires. For telegraph circuits this protector takes the form of a 2,000-volt fuse in each wire. The commoner "protector" such as is used on telephone lines should have the following parts mounted on a porcelain or slate base on which all parts are well insulated: a lightning arrester which will operate at 500 volts or more from a ground wire not less than No. 18 B. & S. gauge; a fuse in each side of the circuit which will blow with small currents (½ to 8 amperes) and will operate well on the voltages likely to reach the protector in case of accident. Where very sensitive instruments are in the circuit, such as contain magnet windings which are easily overheated, there must be a *heat coil* on each side of the line. The heat coil is designed to warm up and melt out with a current large enough to endanger the instruments if continued for a long time, but so small that it would not blow the fuses ordinarily found necessary for such instruments. The smaller currents are often called *sneak* currents. On

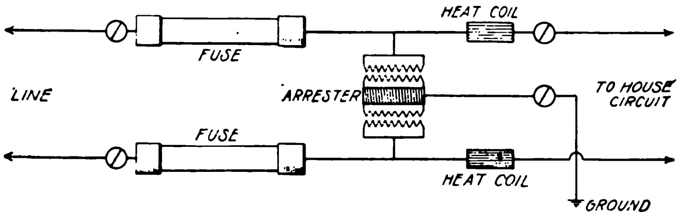


Fig. 135. Circuit Showing Proper Placing of Protecting Devices

those telephone circuits which are supplied with current entirely from the central telephone headquarters sneak or heat coils are not necessary. The fuses must be so placed as to protect the arrester and heat coils, and the protector terminals must be plainly marked *line*, *instrument*, or *ground*.

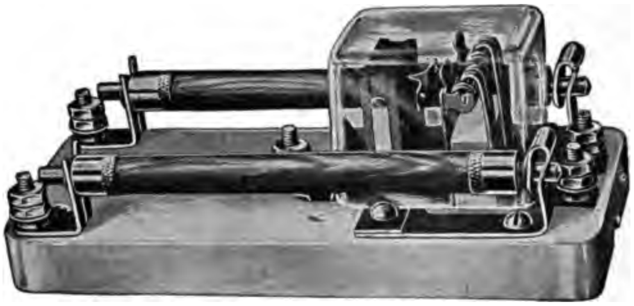


Fig. 136. Common Form of Telephone Protector

The relative arrangement of parts is shown in diagram in Fig. 135 and a common form of protector in Fig. 136.

TESTING

Where possible, two tests of the electric wiring equipment should be made, one after the wiring itself is entirely completed, and switches, cut-out panels, etc., are connected; and another one after the fixtures have all been installed. The reason for this is that if a ground or short-circuit is discovered before the fixtures are installed, it is more easily remedied; and also, because there is no division of the responsibility, as there might be if the first test were made only after the fixtures were installed. If the test shows no grounds or short-circuits before the fixtures are installed, and one does develop after they are installed, the trouble, of course, is that the short-circuit or ground is one or more of the fixtures. As a matter of fact, it is a wise plan always to make a separate test of each fixture after it is delivered at the building and before it is installed.

While a *magneto* is largely used for the purpose of testing, it is at best a crude and unreliable method. In the first place, it does not give an indication, even approximately, of the total insulation resistance, but merely indicates whether or not there is a ground or short-circuit. In some instances, moreover, a magneto test has led to serious errors, for reasons that will be explained. If, as is nearly always the case, the magneto is an alternating-current instrument, it may sometimes happen—particularly in long cables, and especially where there is a lead sheathing on the cable—that the magneto will ring, indicating to the uninitiated that there is a ground or short-circuit on the cable. This may be, and usually is, far from being the case; and the cause of the ringing of the magneto is not a ground or short-circuit, but is due to the capacity of the cable, which acts as a condenser under certain conditions, since the magneto producing an alternating current repeatedly charges and discharges the cable in opposite directions, this changing of the current causing the magneto to ring. Of course, this defect in a magneto could be remedied by using a commutator and changing it to a direct-current machine; but as the method is faulty in itself, it is hardly worth while to do this.

A portable *galvanometer* with a resistance box and Wheatstone bridge, is sometimes employed; but this method is objectionable because it requires a special instrument which cannot be used for many other purposes. Furthermore, it requires more skill and time to use than the *voltmeter* method, which will now be described.

Voltmeter Method. The advantage of the voltmeter method is that it requires merely a direct-current voltmeter, which can be used for many other purposes, and which all engineers or contractors should possess, together with a box of cells having a potential of preferably over 30 volts. The voltmeter should have a scale of not over 150 volts, for the reason that if the scale on which the battery is used covers too wide a range (say 1,000 volts) the readings might be so small as to make the test inaccurate. A good arrangement would be to have a voltmeter having two scales—say, one of 60 and one of 600—which would make the voltmeter available for all practical potentials that are likely to be used inside of a building. If desired, a voltmeter could be obtained with three connections having three scales, the lowest scale of which would be used for testing insulation resistances.

Before starting a test, all of the fuses should be inserted and switches turned on, so that the complete test of the entire installation can be made. When this has been done, the voltmeter and battery should be connected, so as to obtain on the lowest scale of the voltmeter the electromotive force of the entire group of cells. This connection is shown in Fig. 137. Immediately after this has been done, the insulation resistance to be tested is placed in circuit, whether the insulation to be tested is a switchboard, slate panel-board, or the entire wiring installation; and the connections are made as shown in Fig. 138. A reading is again taken of the voltmeter and the leakage is thus obtained, as it is in proportion to the difference between the first and second voltmeter readings. The explanation given below will show how this resistance may be calculated. It is evident that the resistance in the first case was merely the resistance of the voltmeter and the internal resistance of the battery. As a rule, the internal resistance of the battery is so small in comparison with the resistance of the voltmeter and the external resistance, that it may be entirely neglected, and this will be done in the following calculation. In the second case, however, the total resistance in circuit is the resistance of the voltmeter and the battery, *plus* the entire insulation resistance on all the wires, etc., connected in circuit.

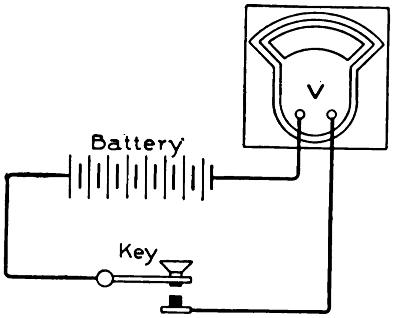


Fig. 137. Connections for Voltmeter Test Before Circuit is Connected

To put this in mathematical form, the voltage of the cells may be indicated by the letter E; and the reading of the voltmeter when the insulation resistance is connected by the circuit, by the letter E'. Let R represent the resistance of the voltmeter and R_x represent the

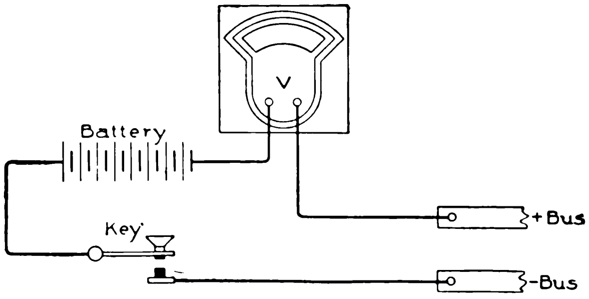


Fig. 138. Connections for Voltmeter Test with the Insulation to be Tested in Circuit

insulation resistance of the installation which we wish to measure. It is a fact which the reader undoubtedly knows, that the e. m. f. as indicated by the voltmeter in Fig. 138 is inversely proportional to the resistance; that is, the greater the resistance, the lower will be the reading on the voltmeter, as this reading indicates the leakage or current passing through the resistance. Putting this in the shape of a formula, we have from the theory of proportion

$$E : E' :: R+R_x : R$$

or

$$E' R+E' R_x=E R$$

Transposing

$$E' R_x=E R-E' R=R (E-E')$$

and

$$R_x=\frac{R (E-E')}{E'}$$

Or, expressed in words, the insulation resistance is equal to the resistance of the voltmeter *multiplied by* the difference between the first reading (or the voltage in the cells) and the second reading (or the reading of the voltmeter with the insulation resistance in series with the voltmeter), *divided by* this last reading of the voltmeter.

Example. Assume a resistance of a voltmeter R of 20,000 ohms, and a voltage of the cells E of 30 volts; and suppose that the insulation resistance test of a wiring installation, including switchboard, feeders, branch circuits, panel-boards, etc., is to be made, the insulation resistance being represented by the letter R_x. By substituting in the formula

$$R_x=\frac{R (E-E')}{E'}$$

and assuming that the reading of the voltmeter with the insulation resistance connected is 5, we have

$$R_x=\frac{20{,}000\times(30-5)}{5}=100{,}000 \text{ ohms}$$

If the test shows an excessive amount of leakage, or a ground or short-circuit, the location of the trouble may be determined by the process of elimination—that is, by cutting out the various feeders until the ground or leakage disappears, and, when the feeder on which the trouble exists has been located, by following the same process with the branch circuits.

Of course, the larger the installation and the longer and more numerous the circuits, the greater the leakage will be; and the lower will be the insulation resistance, as there is a greater surface exposed for leakage. The rules of the Code give a sliding scale for the requirements as to insulation resistance, depending upon the amount of current carried by the various feeders, branch circuits, etc. The rule of the Code covering this point, is as follows:

> The wiring in any building must test free from grounds; *i. e.*, the complete installation must have an insulation between conductors and between all conductors and the ground (not including attachments, sockets, receptacles, etc.) not less than that given below:

Up to 5 amperes	4,000,000 ohms
Up to 10 amperes	2,000,000 ohms
Up to 25 amperes	800,000 ohms
Up to 50 amperes	400,000 ohms
Up to 100 amperes	200,000 ohms
Up to 200 amperes	100,000 ohms
Up to 400 amperes	50,000 ohms
Up to 800 amperes	25,000 ohms
Up to 1,600 amperes	12,500 ohms

> The test must be made with all cut-outs and safety devices in place. If the lamp sockets, receptacles, electroliers, etc., are also connected, only one-half of the resistances specified in the table will be required.

DEVICES AND MATERIALS

No care in installing electrical equipments will entirely compensate for the use of inferior or defective devices or materials. The National Board of Fire Underwriters has for many years maintained a system of tests and examinations of electrical appliances, and issues twice a year a "List of Electrical Fittings" which contains in a classified form under the names of their manufacturers all of the standard and special fittings and materials which have been approved. These tests and examinations are made and the approvals are issued by Underwriters' Laboratories, Inc., a thoroughly equipped institution maintained in Chicago by the fire insurance interests, for the express purpose of examining and testing all kinds of devices and materials, electrical and otherwise, which have any bearing whatsoever on the fire hazard. This "List of Fittings" issued semi-annually, is universally recognized as the only complete and reliable guide to properly safeguarded electrical appliances and it should be consulted and followed in the choice and purchase of supplies. The Underwriters' Laboratories also maintain an elaborate system whereby manufacturers may obtain and place on their wares special labels issued by the Laboratories, which thus become a guarantee on the goods themselves that the articles bearing such labels are in conformity with underwriters' rules and have been examined and tested by special underwriters' inspectors at the factories where they are made. This system of label service and inspection is not yet extended to all classes of approved electrical devices, but for those classes of appliances which are now included, the label may be regarded as affording to prospective purchasers and users reliable evidence not only of the general approval of the design but also that the particular sample bearing the label is made in accordance with requirements and is suitable for use.

The constructional details of electrical fittings and materials together with the chief tests to which they are subjected, prior to approval, are contained in what is known as "Class D" of the Code. This pamphlet should be consulted for full details or inquiry should be addressed to Underwriters' Laboratories, 207 East Ohio Street, Chicago, Illinois, or 135 William Street, New York, for information not given in the Code or in the semi-annual "List of Fittings".

In the following pages is given a brief discussion of the chief characteristics and requirements of some of the more common materials and of the more important classes of devices used in electrical construction work.

RUBBER-COVERED WIRE

General Specifications. A considerable variety of grades of rubber-covered wire is manufactured, some makers offering several grades and others only one or two at most. The chief distinction lies in the quality and quantity of real new, pure, fine rubber gum used in the compound. It is not possible to determine or grade the excellence of a rubber compound by any direct or readily applied tests, but somewhat elaborate tests, physical, chemical, and elec-

TABLE IV

Thickness of Rubber Insulation

B. & S. Gauge	Thickness
18 to 16	1-32 inch
15 to 8	3-64 inch
7 to 2	1-16 inch
1 to 0000	5-64 inch
Circular Mils	
250,000 to 500,000	3-32 inch
500,000 to 1,000,000	7-64 inch
Over 1,000,000	1-8 inch

trical, are necessary to arrive at any correct estimate. The following properties of good wire may, however, be noted. The rubber should be neither hard and dry, nor soft and spongy. When examined minutely it should appear of a close uniform texture free from small bits of unmixed matter or pinholes. It should adhere closely to the tinned copper. The thickness of rubber wall should correspond to the data given in Table IV.

Measurements of insulating wall are to be made at the thinnest portion of the dielectric and it should be very carefully noted whether the copper is exactly centered in the rubber covering so that the full prescribed insulation is maintained on all sides.

The rubber insulation should exhibit a fair degree of elasticity when pieces cut from the wire are stretched and released. If the rubber breaks with a very slight pull and shows no ability to stretch and recover its first length it is probable that a very poor grade of gum has been used, or that the manufacturing process is defective, or both.

After the braid has been carefully removed it should be possible to wind the smaller sizes of wire about a cylinder of the same diameter as the rubber-covered wire without the rubber showing any breaks or cracks either at once or after several days.

The foregoing should be considered as only rough tests and not susceptible of exact application except under conditions which can be maintained in a regular testing laboratory. No directions can be given which will permit any but an expert chemist to make chemical examinations of rubber compounds.

The braids should be of close weave and should be very thoroughly saturated with the compound. All wires should have through their entire length a marker indicating by whom they were made and each coil should bear a tag giving, beside the maker's name, the maximum voltage for which it is designed, the words "National Electrical Code Standard," and the month and year when it was manufactured. Every coil of approved wire is separately tested by the maker at the factory by at least two electrical tests, one designed to show that the insulation is free from mechanical defects and the other to show at least a minimum insulation value.

Special Insulation. Most makers are prepared to furnish at a special price a grade of wire commonly known as "thirty per cent Para." This wire is understood to have an insulation containing at least 30 per cent of "fine, pure, up-river Para" gum which is much more than common commercial rubber-covered wire contains. This 30 per cent wire is also made according to certain rather exacting specifications designed to insure a high grade of insulation with good lasting properties. Wire of this description is often specified where an extra good quality is desired for first class work.

A good compound should contain a large percentage of pure, fine, new rubber of excellent quality. Para rubber is universally admitted to be the best for imparting life, strength, and durability to the insulation. The use of reclaimed rubber or any of the so-called rubber substitutes reduces the excellence of the compound approximately in the proportion in which it is used. The other ingredients of a good compound are solid, waxy, hydrocarbons, suitable mineral matter and sulphur. The sulphur plays an important part in the vulcanizing of the compound, the process whereby the rubber is transformed from its original and almost crude state into the substance familiar to us as manufactured rubber in any one of its numerous forms.

Fixture Wire. Fixtures may be wired with flexible cord or standard rubber-covered wire, and for other wires for use in fixtures, the following rules apply: The wire may be either solid or stranded and not less than No. 18 B. & S. gauge. Solid conductors must be tinned and stranded conductors must be of strands not less than No. 30 B. & S. gauge and must have a cotton wind between copper and rubber. The No. 18 wire may have a rubber insulation $\frac{1}{64}$-inch thick, but No. 16 and also flexible cord used in fixtures must have at least $\frac{1}{32}$-inch rubber. All sizes must be covered with a good braid. The concession of so thin a rubber wall on No. 18 wire has been made because a very small wire must be used to pass through the arms and other parts of many fixtures.

In wiring certain designs of show-case fixtures, ceiling bull's-eyes and similar appliances, in which the wiring is exposed to temperatures in excess of 120° F. (49° C.), from the heat of the lamps, slow-burning wire may be used.

Insulation for Conduit and Armored Circuits. For all conduit work and in all armored cable the wire is regular standard rubber-covered with an extra braid. For twin or duplex wires, this outer braid, which should be at least $\frac{1}{64}$-inch thick, is made as a covering over the two regular rubber-covered and braided conductors. These twin wires are generally used in conduit work but where single conductors are used they must also have double braid. The purpose of this extra outer braid is primarily to withstand the abrasion and strain resulting from hauling the conductors through the conduits from outlet to outlet, and the braids on the individual conductors are to hold the rubber insulation in place and prevent jamming and flattening which might reduce the thickness of rubber between the two wires and thus weaken the insulation at many points.

RIGID CONDUIT AND CONDUIT FITTINGS

Unlined Steel Conduit. The following description applies only to standard unlined steel conduit. This is made of mild steel with a butt weld joint lengthwise of the pipe. Sizes run from normal $\frac{1}{2}$-inch to 4-inch pipe. The raw pipe is thoroughly cleaned inside and outside and then given a protective coating either of an enamel baked on or of zinc applied either by electroplating or by a special process known as sherardizing. With either form of zincing the interior is given a coat of enamel also. The finished pipe should be smoothly coated and able to stand bending without injury to the enamel or the zinc. The conduit should be of sufficiently true circular section to admit of cutting true, clean threads. The enamel applied to conduit is not considered as an insulation but either enamel or zinc is required to protect the steel from rusting away and also to give a smooth surface for the conductors to be drawn over in inserting the wires. Ordinary commercial pipe should never be used as electric conduit since it is not free from rough edges, is not maintained at

TABLE V

Minimum Weights of Conduit for Required Wall Thickness

Size Inches	Pounds per 100 Feet	Size Inches	Pounds per 100 Feet
½	79	1½	249
¾	105	2	334
1	153	3	690
1¼	201		

uniform size or wall thickness, is not protected against rust and in general is not made with the care and rigid inspection which have been found by experience to be necessary for electric conduits. Table V gives the minimum weights per 100 feet of finished conduit which are required to give the specified thickness of wall.

Conduit Fittings. A very great variety of boxes and small fittings for use with conduit is available. All boxes including flush switch boxes should be either of cast iron with walls at least ⅛-inch thick or of sheet steel at least .078 inch thick. They must be well enameled or galvanized to protect them from rusting and must have no openings not closed by the entering pipes, by a metal cover of the same thickness of the box or by the switch, receptacle, or canopy of the device attached to them. Under no circumstances is it allowable to place any such box so that it will not be accessible. There should be no rough edges or corners which are liable to injure the coverings of wires as they are drawn in. Fig. 139 shows the form of a common type of box. Boxes for use with combination gas and electric fixtures must be provided with an arrangement for making a tight electrical connection between the box and the gas pipe at each outlet so that there may be no arcing between box and pipe in case any failure of wire insulation causes a current to flow over the box. Otherwise such an arc may burn a hole in the gas pipe and ignite the gas. All threaded parts of boxes and all threads on locknuts and metal bushings must be clean cut and well fitted in order to insure that permanent and reliable electrical continuity of the conduit system which is one of the chief requirements for conduit work.

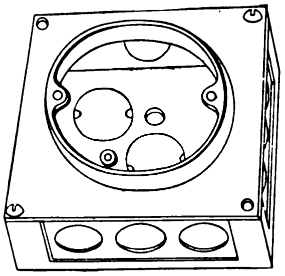


Fig. 139. Common Type of Outlet Box

Set screw connections have been found unsatisfactory as they loosen with the vibration of buildings and with changes of temperature, and only regular screwed thread joints or substantial clamps should be used at all conduit and armored-cable connections.

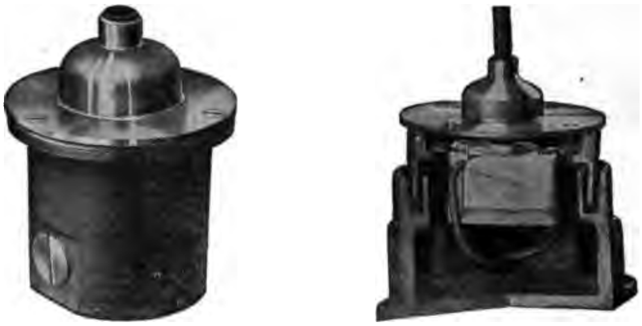


Fig. 140. Common Form of Floor Outlet Box

Where a floor outlet in a conduit system is desired, a special type of box, known as a floor outlet box, should be used, if the fitting is liable to injury or the presence of moisture is probable. Such boxes (see Fig. 140) provide ample room for making splices, for mounting receptacles or other fittings, and especially provide a substantial, water-tight top or cover set flush with the floor surface. The practice of setting flush wall receptacles in floors is allowable in hardwood floors in offices or residences where the mechanical protection need not be great and where water is never used to clean the floors.

FUSES OR CUT-OUTS

Classification. Three forms of fuses are at present employed in this country for general wiring work, *open-link* fuses, *cartridge* fuses and *plug* fuses, the last two being further described as enclosed fuses to distinguish them from the open links. The bases to which or in which the fuses are secured are called cut-outs.

Link fuses are extensively used on large switchboards and their use on such boards is open to less objection than for general wiring since such boards are usually under expert supervision and located in well-protected or fireproof rooms. With link fuses there is always the possibility of a larger fuse being put into the cut-out than it was designed for, which is not true of enclosed fuse cut-outs classified as

TABLE VI
Open-Link Fuse Spacing

	Minimum Separation of Nearest Metal Parts of Opposite Polarity Inches	Minimum Break Distance Inches
125 Volts or less		
10 amperes or less	¾	¾
11-100 amperes	1	¾
101-300 amperes	1	1
301-1000 amperes	1¼	1¼
126 to 250 Volts		
10 amperes or less	1½	1¼
11-100 amperes	1¾	1¼
101-300 amperes	2	1½
301-1000 amperes	2½	2

required below. Again, the voltage in most plants can, under some conditions, rise considerably above the normal. The need of some margin, as a factor of safety to prevent the cut-outs from being ruined in ordinary service, is therefore evident. When tablet-boards or single fuse-blocks with such open-link fuses on them are used in general wiring, they must be enclosed in cabinet boxes. This is necessary, because a severe flash may occur when such fuses melt, so that they would be dangerous if exposed in the neighborhood of any combustible material. Link fuses should never be mounted on porcelain cut-outs because a severe short-circuit is liable to break this rather fragile material and the molten metal is apt to fuse into the porcelain, partly reducing its insulating properties.

There is no filler surrounding the fusible metal of open links and, therefore, the ability of the fuse to open the circuit depends on having enough of the metal burned away, when the fuse blows, to break the arc. For this reason the terminals for link fuses, as far as practicable, should be made of compact form instead of being rolled out in thin strips; and sharp edges or thin projecting pieces, as on wing thumb nuts and the like, should be avoided. Thin metal, sharp edges, and projecting pieces are much more likely to cause an arc to start than a more solid mass of metal. It is a good plan to round all corners of the terminals and to chamfer the edges. Plain fuse wire or fuse strip should never be used for links but only fuses made up with solid metal terminals as shown in Fig. 17.

In general work open-link fuses should not be used on circuits of voltages above 250 volts and where large currents are involved the use of approved circuit breakers is very much to be preferred to extra large link fuses. The spacings for open-link fuses are given in Table VI.

Plug Fuses. The form of fuse which is used in larger numbers than those of any other type, is shown in Fig. 141. Fig. 142 shows one of the many forms of cut-out bases for plug fuses and Fig. 57 shows similar blocks arranged in an asbestos-lined cabinet to make a tablet or panel-board for distributing current to branch-lighting circuits. The cabinet should have a tightly fitted asbestos-lined or metal-lined door. Plug fuses are approved for use only on circuits of not over 125 volts, including 3-wire circuits with grounded neutral, and not over 250 volts between outside wires. Fig. 143 shows the effect if the fuses are blown on a 220-volt circuit. These plugs are limited to ratings of 30 amperes and less because their form and strength is not such as to make them safe for use with larger currents. They are, therefore, chiefly adapted for small lighting and motor branch circuits. They are decidedly safer than open-link fuses of equal capacity and are cheaper than enclosed cartridge fuses.

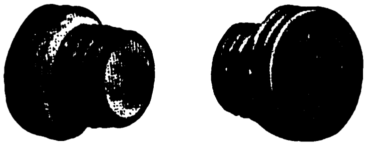


Fig. 141. Standard Fuse Plug

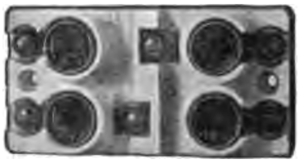


Fig. 142. Cut-Out Base for Fuse Plugs

There are a number of patterns of unapproved plug fuses on the market which should be avoided as they usually lack some of the essential properties of safe fuses, although they may appear from casual inspection to be almost identical with them. It is unfortunately true that plug fuses of the present form can be "doctored" in several ways so as to carry larger currents than they should. Tin-foil, solder, and bits of copper wire are often found put around or into plug fuses so as to completely destroy their usefulness as protective devices. Inspectors and property owners should be on the lookout for this highly dangerous practice and also observe carefully whether plugs of too large current capacity have been substituted for those of ratings which afford real protection to the wiring of the circuits of which they are a part.

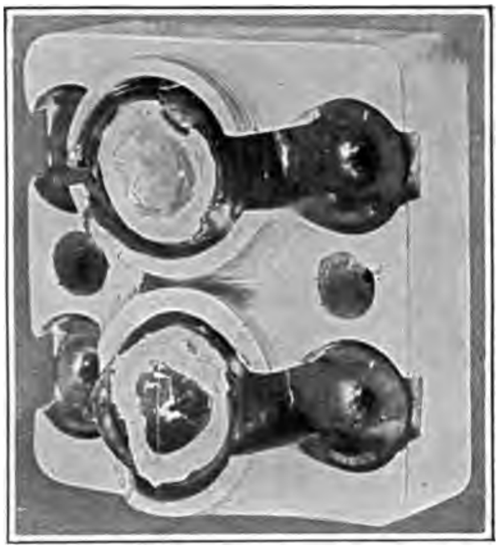
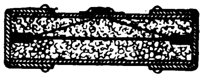
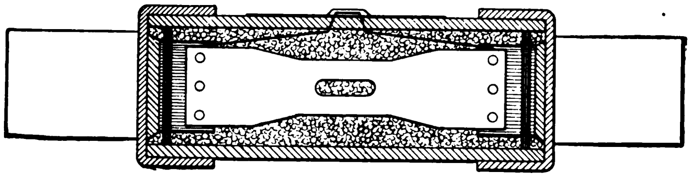


Fig. 143. Effect of Plug Fuses Blown on 220-Volt Circuit

Cartridge Fuses. A cartridge fuse consists of a cylindrical tube of fiber or strong paper to which are fitted metal caps by means of which connection is made to the cut-out terminals. Within the tube is the fusible metal wire or strip extending between and firmly secured to the inside of the caps. The tube is filled with a powdered or granulated material packed closely about the fusible strip. The purpose of this filler is to conduct the heat from the strip to the outer



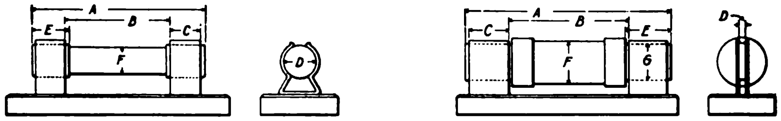
0-30 AMPERES 250 VOLTS



101-200 AMPERES 250 VOLTS

Fig. 144. Sections through Cartridge Fuses Showing Construction

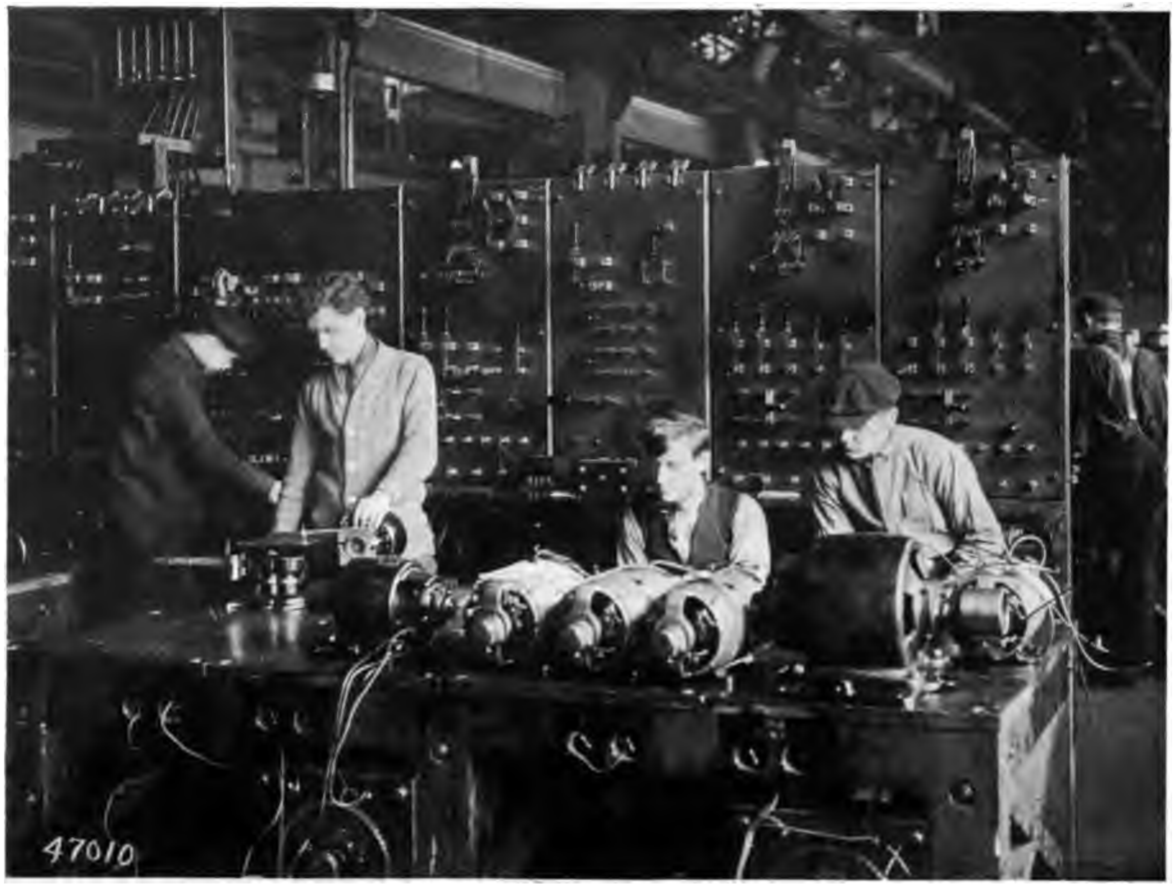
casing, to smother the arc when the fuse blows, to make it possible to adjust more exactly the carrying capacity of the fusible strip, and to absorb some of the gases evolved from the molten metal. The chief ingredients of fillers now used are magnesia and plaster of Paris. Fig. 144 shows in section the internal construction of two typical cartridge fuses of 30 and 200 amperes capacity. The illustration is full size. The small wire extending from one terminal to a point on the tube and thence to the other terminal is designed to burn off at the tube when the fuse blows and fuse a bit of powder under a slip of thin paper on the outside of the casing, thus indicating that the fuse has operated. As will be seen from the description a cartridge fuse will confine the arc, flame, or molten metal within the filler and tube when its fusible element is melted by an overload or by a short-circuit and is, therefore, a safer device than an open-link fuse.


A
B
C
D
E
F
G
STYLE OF TERMINAL FOR CARTRIDGE FUSES 0-60 AMPERES
FORM 1. FERRULE CONTACT
STYLE OF TERMINAL FOR CARTRIDGE FUSES 61-600 AMPERES
FORM 2. KNIFE-BLADE CONTACT

VOLTAGE	RATED CAPACITY AMPERES		A LENGTH OVER TERMINALS INCHES	B DISTANCE BETWEEN CONTACT CLIPS INCHES	C WIDTH OF CONTACT CLIPS INCHES	D DIAMETER OF FERRULES OR THICKNESS OF TERMINAL BLADES INCHES	E MIN. LENGTH OF FERRULES OR OF TERMINAL BLADES OUTSIDE OF TUBE INCHES	F DIAMETER OF TUBE INCHES	G WIDTH OF TERMINAL BLADES INCHES		RATED CAPACITY AMPERES
0-250	0-30	FORM 1	2	1	1/2	9/16	1/2	1/2		FORM 1	0-30
	31-60		3	1 3/4	5/8	13/16	5/8	3/4			31-60
	61-100	FORM 2	5 7/8	4	7/8	1/8	1	1	3/4	FORM 2	61-100
	101-200		7 1/8	4 1/2	1 1/4	3/16	1 3/8	1 1/2	1 1/8		101-200
	201-400		8 5/8	5	1 3/4	1/4	1 7/8	2	1 5/8		201-400
	401-600		10 3/8	6	2 1/8	1/4	2 1/4	2 1/2	2		401-600
251-600	0-30	FORM 1	5	4	1/2	13/16	1/2	3/4		FORM 1	0-30
	31-60		5 1/2	4 1/4	5/8	1 1/16	5/8	1			31-60
	61-100	FORM 2	7 7/8	6	7/8	1/8	1	1 1/4	3/4	FORM 2	61-100
	101-200		9 5/8	7	1 1/4	3/16	1 3/8	1 3/4	1 1/8		101-200
	201-400		11 5/8	8	1 3/4	1/4	1 7/8	2 1/2	1 5/8		201-400

Fig. 145. Dimensions and Classifications of Cartridge Fuses

In 1905 a standardization of cartridge fuses and their cut-out bases was agreed upon in order to bring them all to uniform dimensions, to arrange the different ratings under a classification which would make it impossible to put a large fuse into a cut-out base of a smaller class, and to make it possible to use any approved fuse in any approved base whether fuse and base were of the same or different make. Under this classification two types of terminals were stand-



VIEW IN SMALL MOTOR DEPARTMENT SHOWING TESTING OF SMALL POWER MOTORS
Courtesy of Westinghouse Electric and Manufacturing Company

ardized known as *ferrule* and *knife-blade* contacts, and the current ratings were grouped into two sizes for the ferrule and four sizes for the knife-blade contacts. The dimensions and classification are fully shown on the diagrams and in the table, Fig. 145.

Knife Switches. Knife switches must always be mounted on separate bases of slate, marble, or porcelain, or on slate or marble switchboards or panels. The parts carrying the contact clips and the blade hinges must be secured to the base by two screws, a screw and a dowel-pin, or otherwise, so that the parts will always be in correct alignment. If the contact jaws or hinge clips get turned so as to be out of line, it may be impossible to close the switch, especially at the first attempt, and severe arcing may result from the efforts to do so. Even if the blade enters the jaws, the contact may be imperfect, causing undesirable heating. The chief points to note in judging a knife switch are the following: Excellence of fit of blades both at the hinge and in the contact clips; stiffness and size of all metal parts to secure good contact surfaces and ample carrying capacity. No part should become heated over 50° F. when the switch is carrying its full rated current, and at all sliding contacts there should be at least 1 square inch of surface contact for every 75 amperes of current. The cross bars should be very securely fastened to the blades and the workmanship throughout should be excellent. If each blade is secured to the cross bar by only one screw, without dowel-pins or a square shoulder fitting closely in a recess in the bar, a slight loosening of the screws will allow one blade to close and open the circuit before the other, resulting in arcing and ultimate injury to the switch. Such construction is also liable to result in a weak switch. Too little attention is frequently given the question of mechanical strength, with the result that after a comparatively short time of service the switches rattle to pieces or break unless very carefully handled, and even then repairs are often necessary to keep them in working order. A cheap switch is seldom a rugged, durable device. All switches should be marked with the name of their maker and the rating in both volts and amperes.

The spacings of switches must be at least as great as those given in the Code, a copy of which is given in the following tables. This table specifies the limits necessary for both direct-current and alternating-current systems.

TABLE VII

Approved Spacing and Marking for Knife Switches

Table 1. Not over 125 volts d. c. and a. c.
For switchboards and panel boards:—

	Width and thickness Blades	Clips and Hinges	Minimum separation of nearest metal parts of opposite polarity	Minimum break distance
30 amperes	½ x 5/64 Inch	½ x 3/64 Inch	1 Inch	¾ Inch
60 amperes			1¼ Inch	1 Inch

Table 2. Not over 125 volts d. c. and a. c.
For individual switches:—

	Inch	Inch	Inch	Inch
30 amperes	½ x 5/64	½ x 3/64	1¼	1
60 and 100 amperes			1½	1¼
200 amperes			2¼	2
400 and 600 amperes			2¾	2½
800 and 1000 amperes			3	2¾

A 300-ampere switch with the spacings of the 200-ampere switch above may be used on switchboards.

Table 3. 250 volts only d. c. and a.
For all switches:—

	Inch	Inch	Inch	Inch
30 amperes	½ x 5/64	½ x 3/64	1¾	1½

Table 4. Not over 250 volts d. c. nor over 500 volts a. c.
For all switches:—

	Inch	Inch	Inch	Inch
30 amperes	⅝ x ⅛	⅝ x 1/16	2¼	2
60 and 100 amperes			2¼	2
200 amperes			2½	2¼
400 and 600 amperes			2¾	2½
800 and 1000 amperes			3	2¾

A 300-ampere switch with the spacings of the 200-ampere switch above may be used on switchboards.

Cut-out terminals on switches for over 250 volts must be designed and spaced for 600-volt fuses.

Table 5. Not over 600 volts d. c. and a. c.
For all switches:—

	Inch	Inch	Inch	Inch
30 amperes	⅝ x ⅛	⅝ x 1/16	4	3½
60 amperes			4	3½
100 amperes			4½	4

Auxiliary contacts of either a readily renewable or a quick-break type or the equivalent are recommended for d. c. switches, designed for over 250 volts, and must be provided on d. c. switches designed for use in breaking currents greater than 100 amperes at a voltage of over 250.

For 3-wire direct-current and 3-wire single-phase systems, the separation and break distances for plain 3-pole knife switches must not be less than those required in the above table for switches designed for the voltage between neutral and outside wires.

Marking. Must be plainly marked where it can be read, when the switch is installed, with the name of the maker and the current and the voltage for which the switch is designed.

Switches designed for 250-volt d. c. or 500-volt a. c. circuits, without fuses on the switch base, must be marked 250 V., d. c., 500 V., a. c. When 250-volt fuse terminals are mounted on the switch base the marking of the switch must be 250 V., d. c. and a. c. When 600-volt fuse terminals are mounted on the switch base the terminals must be spaced for 600-volt fuses and the switches marked 500 volts a. c.

Triple pole switches designed with 125-volt spacings between adjacent blades must be marked 125 volts and may be used on 3-wire d. c. or single phase systems having not more than 125 volts between adjacent wires and not more than 250 volts between the two outside wires.

When designed with 250-volt spacings between adjacent blades, triple poles switches must be marked 250 volts and may be used on 3-wire d. c. or single-phase systems having not more than 250 volts between adjacent wires and not more than 500 volts between the outside wires.

Snap Switches. Under this term are included the *common round base surface* switches, the *rotary* and *push-button* switches, which are set in boxes in side walls flush with the surface, *pendant* switches, and all such as are operated by the motion of doors, by a cord and all switches mounted on fixtures. The distinguishing feature of them all consists in the fact that the motion of the parts which open and close the circuit is produced by a spring contained in the mechanism. As the handle or button is turned or pushed this spring is wound up and at the proper tension is released, thus throwing the switch blades into or out of the contacts. Thus the quickness with which the circuit is opened or closed is not directly determined by the motion of the operator's hand but by the spring, and if the switch is of proper design and in good condition, the action is prompt and reliable even though the person using the switch is not careful to do just the right thing. Such snap switches, therefore, differ from knife-blade switches in that their proper use does not depend upon the user and they are correspondingly better suited for general purposes for unskilled persons.

The bases should be of non-combustible material, usually porcelain, and all covers should be lined with a non-conducting material such as fiber unless they are of porcelain. Without this lining there is danger of the cover forming a short-circuit in the switch, especially if the cover is removed or replaced while the switch is "alive." The side lining should extend beyond the lower edge of the cover.

The binding posts should be of a type in which the end of the connected wire is held under a screw head or equivalent device and not by a set-screw the end of which drives against the side of the wire, as a set-screw is likely to become loosened and is almost sure to cut into the wire. Indicating switches are much preferred for all work, as by showing at once whether the current is "on" or "off" they tend to save mistakes and possible accidents. The fact that lights do not burn or that a motor does not run is not necessarily a sure sign that the current is off, but the indicating switch makes it possible to tell at a glance whether the circuit is open or closed.

Fig. 146 shows a variety of approved snap switches of common type. Snap switches to be approved are required to operate successfully at 50 per cent excess current above that for which they are rated at the voltages for which they are designed. This is to provide a margin of safety but should not be made an excuse for using them for larger currents than those marked on them. They are made in a great variety of sizes and patterns, single- and double-pole, three- and four-way, and in special designs for turning on the lamps of a chandelier one after the other or for controlling small motors or heating devices. The standardized ratings include 125, 250, and 600 volts for currents of 3, 5, and 10 amperes in the more commonly used patterns. Certain large-sized double-pole surface snap switches are rated at 20 or 30 amperes while a few of the more special and less substantial forms are limited to 1 ampere only. In judging snap switches of all kinds samples are tested by Underwriters' Laboratories in the following way: they are connected to control groups of lamps taking full rated current of the switch at full rated voltage and are then put on a special machine which operates them slowly and continuously for 6,000 cycles, that is 6,000 full "on and off" operations. It is required that the samples stand this endurance test without failing either mechanically or electrically. This test is re-applied to new and recent samples from time to time, and similar

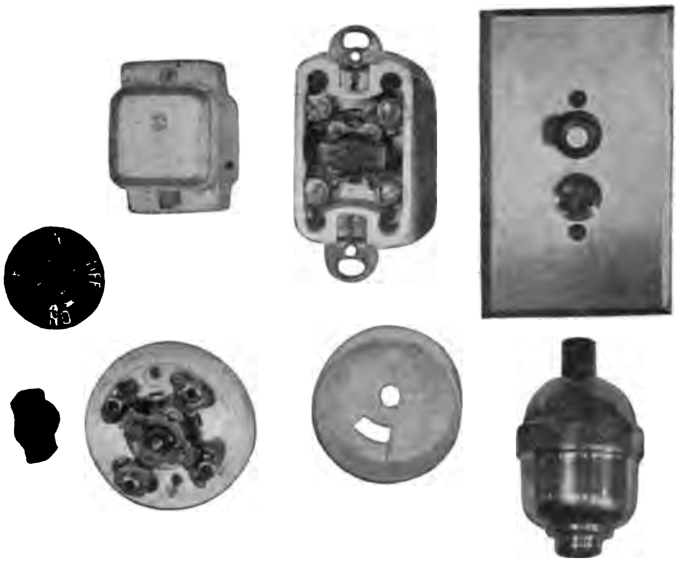


Fig. 146. Group of Approved Snap Switches

tests are constantly in progress at the factories where the switches are made, so that any important defect in material or construction is soon detected and a fairly uniform grade of snap switches is sure to be produced for the user. Such persistent tests have done much to improve the quality of these and other electrical products.

CIRCUIT BREAKERS

Circuit breakers are automatic switches so designed that an excess current will cause the switch to open. They thus share the properties of both switches and protective devices such as fuses, and in their choice and installation both functions must be considered. Breakers are made for currents of all capacities and for circuits of every voltage both d. c. and a. c. Those most commonly used on lighting and power switchboards and in general commercial work are for voltages of 600 volts or less (occasionally 2,000 volts). For higher voltages the breakers are of massive form and are often set in *cells* or compartments of brick, slate, or concrete. Such breakers are employed only where expert supervision is always available and their form and operation is, therefore, not prescribed by underwriters' rules but rather by the engineering necessities of the system of which they are a part.

The ordinary commercial breaker as used on low-voltage circuits may be one, two, or three poles and these may be independent of each other or may be interlocked so that an overload on any one wire will cause all the lines to be opened. The latter is preferable. Breakers are usually made with an adjustment regulating the point at which they will open. Thus a 100-ampere breaker may be set to open at any current with a certain range above and below 100 amperes.

In installing breakers the same care should be taken as with fuses of like capacity. They should never be placed near any inflammable material, as their operation under severe overloads results in a severe though brief arc and often in the spattering of bits of molten metal quite capable of igniting waste, shavings, etc. The use of circuit breakers instead of fuses is to be recommended for very large currents and for all circuits such as many motor circuits where operating conditions are liable to produce frequent overloads.

Classification. Circuit breakers may be divided into two chief classes, *carbon* or *air-break* patterns and *oil-immersed* patterns. The former may be used on either d. c. or a. c. circuits. They have copper blades and fixed contacts with carbon secondary contacts arranged to open just after the heavy copper contacts. Thus the current is carried by copper parts of ample size when the breaker is closed, and the arcing on opening is largely confined to the carbon contacts which are better for this purpose than metal. Such breakers may become dangerous either from overheating of the coils, from arcing upon opening heavy currents, or from failure to act in emergency as they are intended to do. However, the better types of modern breaker are very well made and form reliable protective devices.

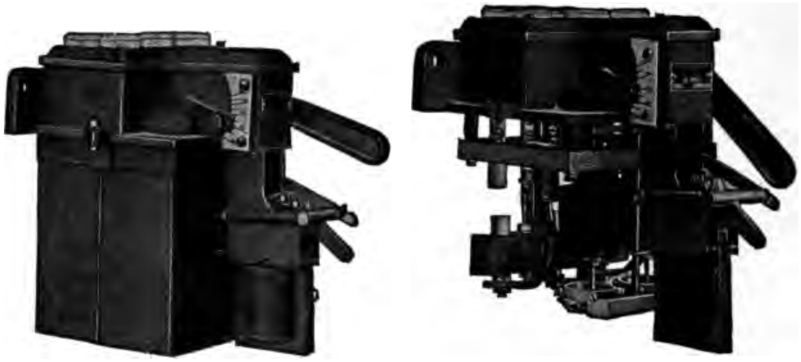


Fig. 147. Modern Oil Circuit Breaker

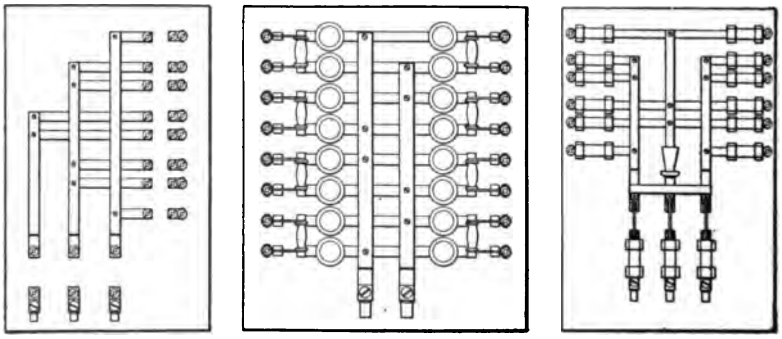


Fig. 148. Typical Panel-Board Bus-Bar Arrangements

Oil-immersed breakers are coming more and more into use. They are made with their contacts immersed in a heavy oil contained in a can or case of suitable form. When the contacts open, the oil aids very greatly in quenching the arc, and such breakers can, therefore, be made quite compact since a long break distance is not so essential. These breakers are made both for switchboards and wall mounting. They are not so well suited to direct-current circuits since the action of the d. c. arc carbonizes the oil too rapidly. Fig. 147 shows a modern oil breaker. They present a hazard due to the oil which may become overheated or even ignited. This is unlikely to occur with a well designed oil switch or breaker, but the usual precautions should be taken to keep the switch and its immediate neighborhood clean and free from accumulations of rubbish or any inflammable material which may become oil soaked.

MISCELLANEOUS DEVICES

Panel Boards and Cabinets. Panel boards are distributing boards, or switchboards from which the branch circuits are led off from the mains. They must have slate bases on which are mounted the necessary bus bars, switches and fuses. A very great variety of panels is made, the arrangement of parts in a few patterns being shown in Fig. 148, while a complete panel set in a steel cabinet is shown in Fig. 149. Fig. 150 shows the wiring channel often provided and a cabinet with wood door and trim. The panel base and the two partitions shown in the section drawing are of slate and all other interior surfaces of the cabinet including the door should be lined with sheet steel.

Wood cabinets should not be used on conduit, armored cables, or metal molding systems of wiring as they do not form a metallic connection between parts of the system and any attempt to overcome this by bonding around the box by wire is not liable to result in a good job. Metal cabinets are preferable in all cases except possibly in very damp locations where they are liable to rust rapidly. All cabinets whether for panels or for individual switches or cut-outs should be thoroughly dust tight and fitted with tightly-closing doors. No metal thinner than No. 16 U. S. Metal Gauge should be used and heavier metal is necessary for all but the smaller sizes of box to secure the requisite stiffness and durability.

Sockets and Receptacles. The almost endless variety of these fittings may be classified in various ways, as for dry or for wet places; key and keyless types; brass shell or porcelain types; conduit boxes; molding signs; miniature and candelabra sockets and receptacles, etc. All standard sockets and receptacles are now made with what are called Edison screw-shells into which the base of the incandescent lamp is screwed, the *shell* being connected in the socket to one of the lead wires and the *center contact* to the other lead wire. In all types the design of the socket or receptacle should be such that when a lamp is inserted there will be no current-carrying part of the lamp base exposed. This calls for a minimum depth of the socket of $\frac{15}{16}$ inch and sockets and receptacles which do not have such depth should not be used. Sockets and receptacles were formerly rated in candle-

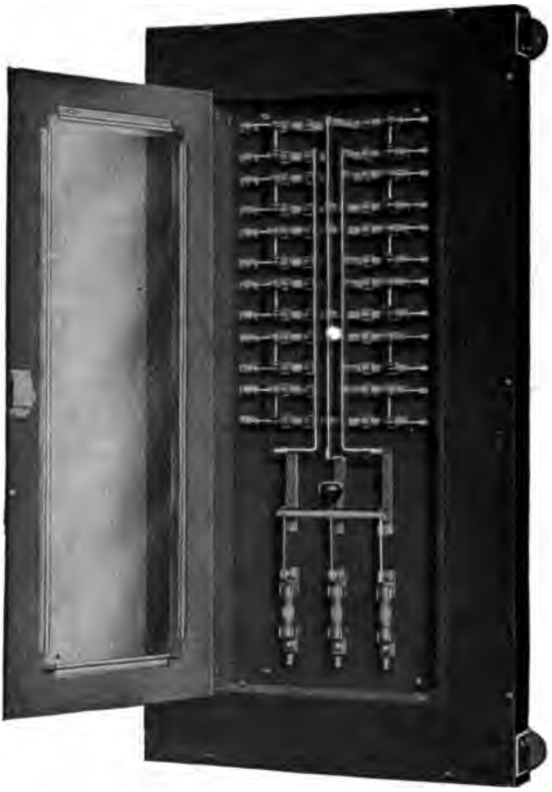


Fig. 149. Complete Panel Board in Steel Cabinet

power of the lamps designed for them or in amperes and volts but the introduction of the newer high-efficiency lamps such as the tungsten and nitrogen-filled lamps has rendered this method of rating inapplicable. All key or pull sockets and receptacles of standard types are now rated 250 watts 250 volts, or 660 watts 250 volts, with the added stipulation that this rating shall not be interpreted as permitting the use at any voltage of current above 2½ amperes, or 6 amperes, respectively.

Keyless sockets and receptacles of standard types are rated 660 watts, 250 volts, but not over 6 amperes at any voltage.

Miniature and candelabra sockets are rated 75 watts, 125 volts.

The new so-called "Mogul" sockets are rated at 1500 watts 250 volts and are for the larger sizes of lamps.

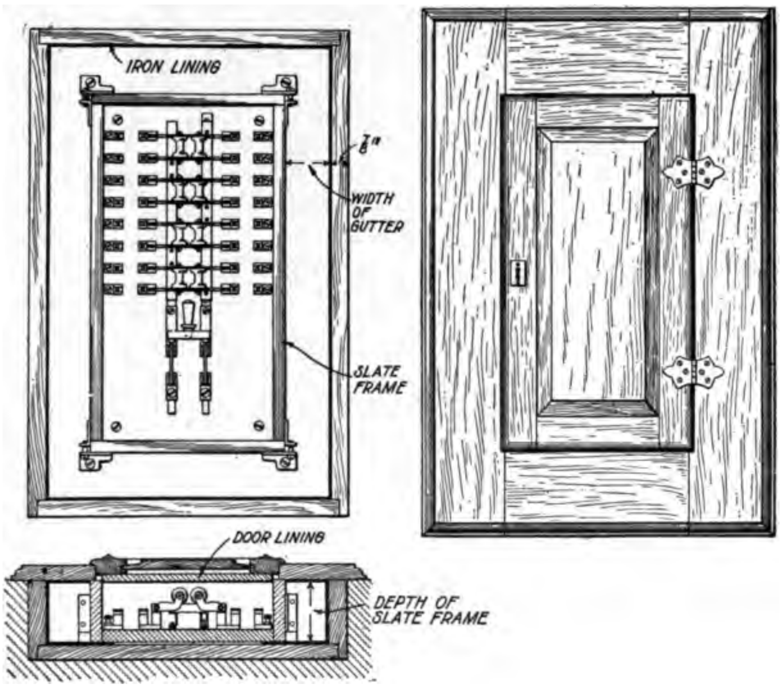


Fig. 150. Panel Board and Wood Cabinet Showing Method of Construction

Weatherproof sockets having no exposed current-carrying parts may be rated 660 watts, 600 volts, and thus may be used in series on 600-volt circuits.

The most common abuse of sockets is to employ them as outlets for currents far in excess of what they or the wiring immediately connected to them should carry and the above limits should be rigidly adhered to. The assigned ratings do not imply that the full power can be taken from each and every socket on a circuit at once. Thus twelve carbon 16 c. p. lamps in sockets may take 6 amperes on a 110-volt circuit and be fused with 6-ampere fuses. At 250 watts per socket, twelve sockets will take 3,000 watts which, at 110 volts, is over 27 amperes, an amount of power forbidden by the rules limiting lighting branch circuits to 660 watts and a current manifestly too large for the No. 14 wire which would usually be used on such a circuit. The ratings 250 watts, 250 volts, for key sockets, and 660 watts, 250 volts, for keyless sockets, are intended to express the maximum safe carrying capacity of each socket or receptacle alone and do not warrant employing them in the manner indicated above, which would seriously overload ordinary circuits.

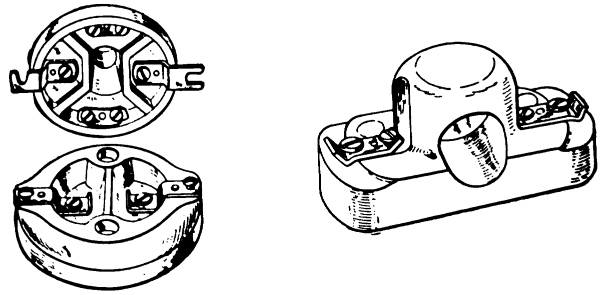


Fig. 151. Common Types of Fused and Unfused Rosettes

Rosettes. These devices are usually of porcelain and provide a means of connecting flexible cords to the main or branch circuits. Types are made either with or without small link fuses in the base but the unfused type is much to be preferred and should be used exclusively in general work since the use of link fuses in porcelain fittings is undesirable because of the possible results following a short-circuit blowing the fuses violently. It is much better to place all fuses at distribution centers, such as panel boards, and by keeping the fuses of proper capacity, depend on them for protection rather than on fuses scattered about in fittings, rosettes, etc. Fig. 151 shows common types of fused and unfused rosettes.

Bell-Ringing Transformers. Within the last few years small transformers have been brought out designed for the purpose of ringing door bells or for other light signaling work, deriving their power for such service directly from alternating-current lighting circuits in houses. They take the form of small, totally enclosed transformers with two very thoroughly insulated coils, the primary coil to be connected directly across an alternating circuit and the secondary to be connected to the bell circuit as shown in Fig. 152.

The push button is, of course, usually open so that no current flows over the bell circuit. When the button is pushed a current of low voltage (10 to 20 volts) and small ampere capacity (not over 2 amperes) flows over the secondary or bell circuit, the power being derived from the primary winding connected to the alternating-current line as in the case of any transformer. Absolutely no dependence can be put upon the insulation of the bell circuit which is often of cotton-covered paraffined wire (annunciator wire) installed in the most unreliable manner and the bells and push buttons are not designed for anything but very low voltage currents. It is, therefore, imperative that the design and construction and insulation of the transformer be such that under no conditions, either of service or from an accident, can the 110-volt current act directly on the bell circuit. Furthermore, the design of the transformer must be such that even if the push button be left closed or the bell wires become short-circuited only a very small current will flow over the bell wiring. In approved bell-ringing transformers both these results are secured with reasonable safety.

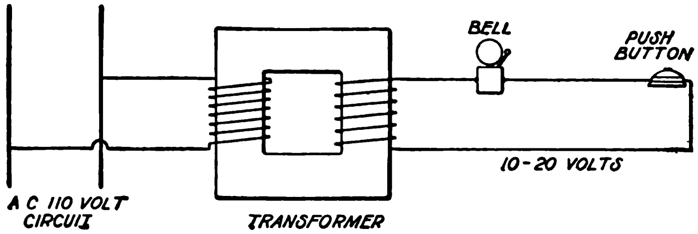


Fig. 152. Diagram of Simple Transformer Circuit

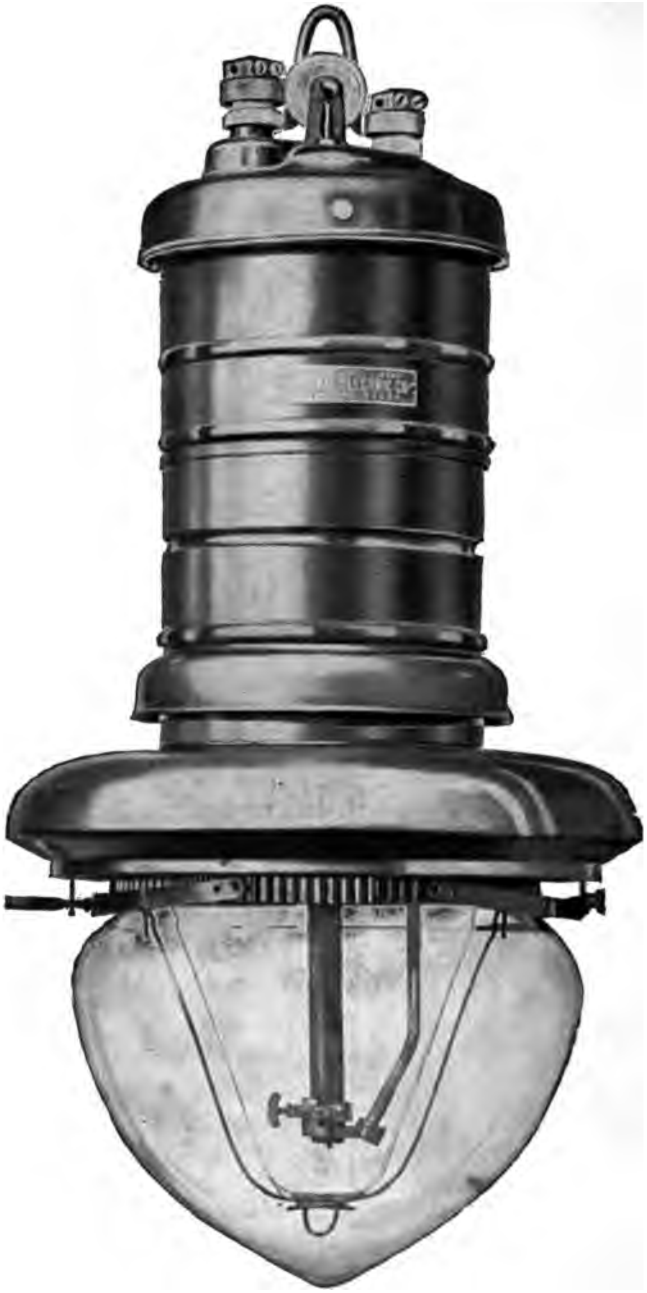
Heating Devices. The rapid introduction of all sorts of electric heating devices for domestic and industrial use has brought with it a special hazard which it is peculiarly difficult to control. These devices are useful only as they are capable of developing a considerable heat in a short time. The normal use, of course, tends to draw away the heat and thus prevent a dangerously high temperature being reached, but if these devices are left connected to the circuit and unused, many of them will reach a dull red heat and may thus become a serious fire hazard. This is true of electric flatirons especially and also of many cooking utensils and other apparatus for domestic or light factory use. It is evident, therefore, that all such heating appliances should be made wholly of non-combustible material and, so far as their use will permit, be fitted with legs, guards, or other parts which will keep the heated parts well separated from walls, floors, tables, etc.

Stationary heating devices should be installed only when every precaution has been taken and the fact that perhaps only a low temperature will be produced by the proper and normal operation of the heater should not be made an excuse for omitting any of the precautions that would be taken for the higher temperatures which may easily result from accident or misuse. There should be ample air spaces and proper protection of adjacent surfaces by asbestos board and metal sheathing. In general all electric heating devices must be installed and used as possible sources of great heat.

Portable heating devices are not easily protected from misuse or accident. The chief protection against fires from such appliances appears to depend upon the original excellence of design and construction of the devices themselves, the fact that many of them employ but a small amount of energy, and, finally, upon a slowly growing appreciation by users and the public generally, that electrically-heated appliances, while usually fairly safe, if properly used, may very readily become dangerous if abused or improperly used.

Electric Gas Lighters. A battery, spark coil, and similar appliances are often used for the purpose of lighting the gas on gas fixtures without the use of matches. In such installations the wires from the battery and coil are led to the fixtures in any convenient manner and on the fixtures themselves small wires are carried down the outside of fixture stems and arms to the burners. The line wires are not insulated or installed in a manner comparable as to safety with electric light wires, and on the fixtures the insulation is especially weak and exposed to injury. It is, therefore, evident that such gas-lighting systems should never be installed on the same fixture with electric lights, since a breakdown is very liable to permit the electric-light current to pass over the gas-lighting wires and cause a fire at some point perhaps concealed in a partition, either from overheating the small wires or from arcing to other wires or to grounded metal piping.

Marine Work. The Code contains special rules governing the installation of electric light and power wires and apparatus on shipboard. These differ from the standard rules in only a few particulars, as indicated by the need of special care to provide against the effects of constant and severe vibration, dampness and extreme hard usage to which marine installations are always subjected. The provisions of the Code should be referred to in detail by those who are called upon to install or inspect work of this special type.



GENERAL ELECTRIC MULTIPLE LONG-LIFE FLAME ARC LAMP
Courtesy of General Electric Company

ELECTRIC LIGHTING

HISTORY AND DEVELOPMENT

The history of electric lighting as a commercial proposition begins with the invention of the Gramme dynamo by Z. J. Gramme, in 1870, together with the introduction of the Jablochkoff candle or light, which was first announced to the public in 1876, and which formed a feature of the International Exposition at Paris in 1878. Up to this time, the electric light was known to but few investigators, one of the earliest being Sir Humphrey Davy who, in 1810, produced the first arc of any great magnitude. It was then called the *voltaic arc,* and resulted from the use of two wood charcoal pencils as electrodes and a powerful battery of voltaic cells as a source of current.

From 1840 to 1859, many patents were taken out on arc lamps, most of them operated by clockwork, but these were not successful, due chiefly to the lack of a suitable source of current, since all depended on primary cells for their power. The interest in this form of light died down about 1859, and nothing further was attempted until the advent of the Gramme dynamo.

The incandescent lamp was but a piece of laboratory apparatus up to 1878, at which time Edison produced a lamp using a platinum spiral in a vacuum, as a source of light, the platinum being rendered incandescent by the passage of an electric current through it. The first successful carbon filament was made in 1879, this filament being formed from strips of bamboo. The names of Edison and Swan are intimately connected with these early experiments.

From this time on, the development of electric lighting has been very rapid and the consumption of incandescent lamps alone has reached several millions each year. When we compare the small amount of lighting done by means of electricity twenty-five years ago with the enormous extent of lighting systems and the numerous applications of electric illumination as they are today, the growth and development of the art is seen to be very great and the value of a study of this subject may be readily appreciated. Electricity may not always furnish the cheapest light, but its admirable qualities and its convenience of operation make it by far the most desirable.

CLASSIFICATION

The subject of electric lighting may be classified as follows:

(1) The type of lamps used.
(2) The methods of distributing power to the lamps.
(3) The use made of the light or its application.
(4) Photometry and lamp testing.

The types of lamps used may be subdivided into:

(1) Incandescent lamps: carbon and metallic filament.
(2) Special lamps: exhausted bulb without filament, such as the Cooper-Hewitt lamp and the Moore tube lamp.
(3) Arc lamps: ordinary carbon and flaming arc.

INCANDESCENT LAMPS

Historical. The incandescent lamp is by far the most common type of lamp used and the principle of its operation is as follows:

If a current of I amperes is sent through a conductor whose resistance is R ohms for a time t seconds, the conductor is heated, the heat generated being expressed in joules or watt-seconds thus:

$$\text{Heat generated} = I^2 R\, t$$

If the current, material, and conditions are so chosen that the substance may be heated in this way until it gives out light, i. e., becomes incandescent and does not deteriorate too rapidly, we have an incandescent lamp. Carbon was the first successful material to be chosen for this conductor and for a long time all attempts to substitute another substance in place of carbon failed. Within the last few years metallic filament lamps have been introduced commercially with great success and the carbon incandescent lamp is now only used for special purposes such as in the case of very low candle-power units operated at commercial voltages.

Tungsten lamps are now used in the majority of cases and these and other types which have proved entirely or partially successful will be treated later. The present form of carbon incandescent lamp has, however, been much improved over the first forms and, owing to the historical importance of this lamp, the method of manufacture will be briefly considered.

CARBON FILAMENT LAMPS

ORDINARY TYPE

Method of Manufacture. *Preparation of the Filament.* Cellulose, a chemical compound rich in carbon, is prepared by treating absorbent cotton with zinc chloride in proper proportions to form a uniform gelatine-like mass. This material is then forced, "squirted", through steel dies into alcohol, the alcohol serving to harden the soft transparent threads, which are then dried, cut to the desired lengths, wound on forms, and carbonized by heating to a high temperature away from air. During carbonization, the material becomes hard and stiff, assuming a permanent form; after cooling, the filaments are removed, measured, and inspected.

Mounting the Filament. After carbonization, the filaments are mounted or joined to wires leading into the globe or bulb. These wires are made of platinum—platinum being the only conductor, so far as known, that expands and contracts the same as glass with change in temperature and which, at the same time, will not be melted by the heat developed in the carbon. Since the bulb must remain air-tight, a substance expanding at a different rate from the glass cannot be used. The filament is fastened to the *leading-in* wires by means of the pasted joint. Finely powdered carbon is mixed with some adhesive compound such as molasses, and this mixture is used as a paste for fastening the carbon to the platinum. Later, when current is sent through the joint, the volatile matter is driven off and only the carbon remains. This makes a cheap and, at the same time, a very efficient joint.

Flashing. Filaments, prepared and mounted in the manner just described, are fairly uniform in resistance, but it has been found that their quality may be much improved and their resistance very closely regulated by depositing a layer of carbon on the outside of the filament by the process of flashing, i. e., heating the filament to a high temperature in a hydrocarbon gas, such as gasoline vapor, under partial vacuum. Current is passed through the filament to accomplish the heating. The effects of flashing are as follows:

(1) The diameter of the filament is increased by the deposited carbon and hence its resistance is decreased. The process must be discontinued when the desired resistance is reached. Any little irregularities in the filament will

be eliminated since the smaller sections, having the greater resistance, become hotter than the remainder of the filament and the carbon is deposited more rapidly at these points.

(2) The surface is changed from a dull black and comparatively soft coating to a bright gray and much harder one, and which increases the life and efficiency of the filament.

Exhausting the Bulb. After flashing, the filament is sealed in the bulb and the air exhausted through the tube A in Fig. 1, which shows the lamp in different stages of its manufacture. The exhaustion is accomplished by means of mechanical air pumps, supplemented by Sprengle or mercury pumps and chemicals. Since the degree of exhaustion must be high, the bulb should be heated during the process so as to drive off any gas which may cling to the glass. Exhaustion is necessary for several reasons:

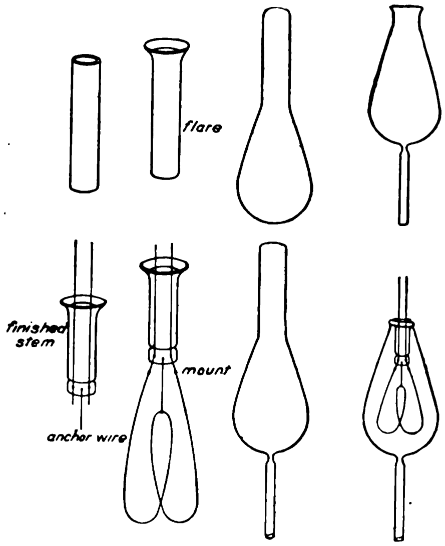


Fig. 1. Different Stages in the Manufacture of an Incandescent Lamp

(1) To avoid oxidization of the filament.

(2) To reduce the heat conveyed to the globe.

(3) To prevent wear on the filament due to currents or eddies in the gas.

After exhausting, the tube is sealed off and the lamp completed for testing by attaching the base by means of plaster of Paris.

Voltage and Candle-Power. Incandescent lamps of the carbon type vary in size from the miniature battery and candelabra lamps to those of several hundred candle-power, though the latter are very seldom used. The more common values for the candle-power are 8, 16, 25, 32, and 50, the choice of candle-power depending on the use to be made of the lamp.

The voltage will vary, depending on the method of distribution of the power. For what is known as "parallel distribution", 110 or 220 volts are generally used. For the higher values of the voltage, long and slender filaments must be used, if the candle-power is to be low; and lamps of less than 16 candle-power for 220-volt circuits are not practical, owing to difficulty in manufacture. For series distribution, a low voltage and higher current is used; hence the filaments may be somewhat heavy. Battery lamps operate on from 4 to 24 volts, but the vast majority of lamps for general illumination are operated at 110 volts, or thereabouts.

Efficiency. By the efficiency of an incandescent lamp is meant the power required at the lamp terminals per candle-power of light given. Thus, if a lamp giving an average horizontal candle-power of 16 consumes $\frac{1}{2}$ an ampere at 112 volts, the total number of watts consumed will be $112\times\frac{1}{2}=56$, and the watts per candle-power will be $56 \div 16 = 3.5$. The efficiency of such a lamp is said to be 3.5 watts per candle-power, or simply watts per candle. *Watts economy* is sometimes used for *efficiency*.

The efficiency of a lamp depends on the temperature at which the filament is run. In the ordinary lamp this temperature is between 1280° and 1330° centigrade, and the curve in Fig. 2 shows the increase of efficiency with the increase of temperature. The temperature attained by a filament depends on the rate at which heat is radiated and the amount of power supplied. The rate of radiation of heat is proportional to the area of the filament, the elevation in temperature, and the emissivity of the surface.

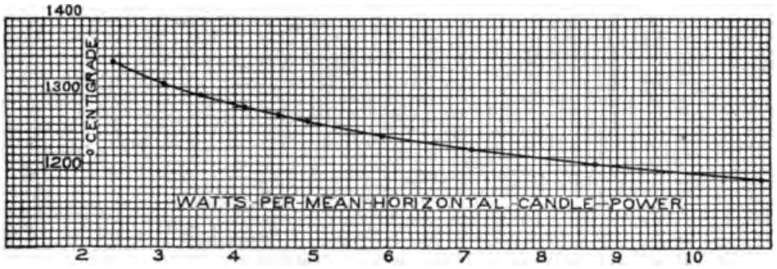


Fig. 2. Variations in Efficiency of an Incandescent Lamp with Temperature

By emissivity is meant the number of heat units emitted from unit surface per degree rise in temperature above that of surrounding bodies. The bright surface of a flashed filament has a lower emissivity than the dull surface of an unheated filament; hence less energy is lost in heat radiation and the efficiency of the filament is increased.

As soon as incandescence is reached, the illumination increases much more rapidly than the emission of heat; hence the increase in efficiency shown in Fig. 2. Were it not for the rapid disintegration of the ordinary carbon filament at high temperature, an efficiency higher than 3.1 watts could be obtained. By a special treatment of the carbon filaments, the nature of the carbon is so changed that the filaments may be run at a higher temperature and the lamps may still have a life comparable to that of the 3.1-watt lamp. Lamps using these special carbon filaments are known as "gem metallized filament lamps", or merely as "gem lamps", and they will be described more fully later.

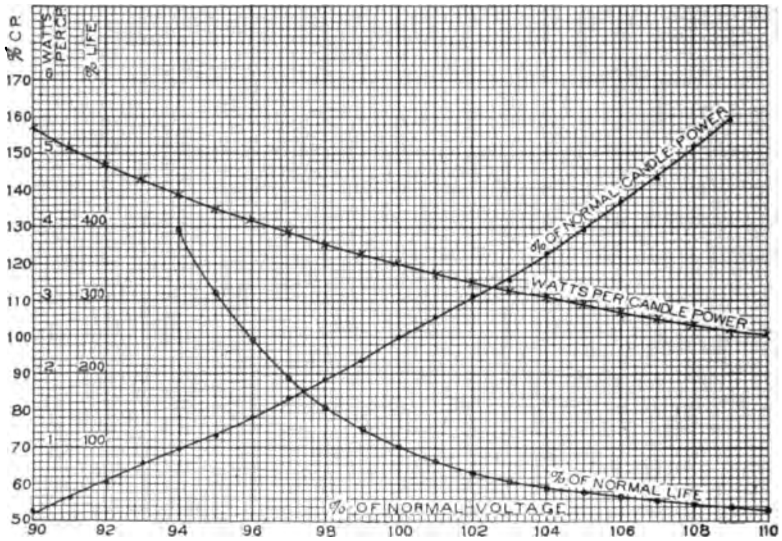


Fig. 3. Curves of Efficiency and Life of Carbon Filament Lamp

Relation of Life to Efficiency. By the useful life of a lamp is meant the length of time a lamp will burn before its candle-power has decreased to such an extent that it would be more economical to replace the lamp with a new one than to continue to use it at its decreased value. A decrease to 80 per cent of the initial candle-power of carbon lamps is now taken as the point at which a lamp should be replaced and the normal life of a lamp is in the neighborhood of 800 hours. The curves in Fig. 3 show the relation between voltage, candle-power, efficiency, and life for the ordinary carbon lamp. These curves show that a 3 per cent increase of voltage on the lamp reduces the life by one-half, while an increase of 6 per cent causes the useful life to fall to one-third its normal value. The effect is even greater when 3.1 watt lamps are used, but not so great with 4-watt lamps. From this we see that the regulation of the voltage used on the system must be very good if high efficiency lamps are to be used, and this regulation will determine the efficiency of the lamp to be installed.

Lamps should always be renewed at the end of their useful life—this point being termed the "smashing point"—as it is cheaper to replace the lamp than to run it at the reduced candle-power. Some recommend running these lamps at a higher voltage, but that means at a reduced life, and it is not good practice to do this.

Fig. 4 shows the life curves of a series of carbon incandescent lamps. These curves show that there is an increase in the candle-power of some of the lamps during the first 100 hours, followed by a period during which the value is fairly constant, after which the light given by the lamp is gradually reduced to about 80 per cent of the initial candle-power.

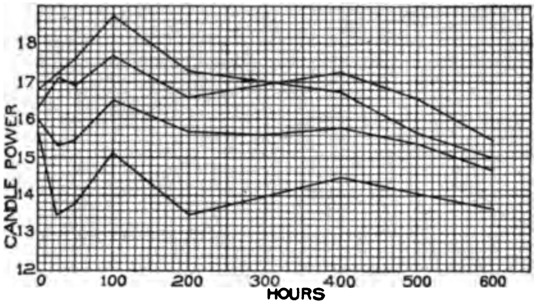


Fig. 4. Life Curves of Carbon Incandescent Lamps

GEM METALLIZED FILAMENT TYPE

Nature of Improvement. When the incandescent lamp was first well established commercially, the useful life of a unit, when operated at 3.1 watts per candle, was about 200 hours. The improvements in the process of manufacture have been continuous from that time until now and the useful life of a lamp, operated at that efficiency to-day, is in the neighborhood of 500 hours. Experiments in the treatment of the carbon filament have led to the introduction

TABLE I

Life and Efficiency Ratings of Gem Lamps at the Three Operating Efficiencies

Size of Lamp in Watts	HIGH EFFICIENCY		MEDIUM EFFICIENCY		LOW EFFICIENCY	
	W.P.C.	Average Total Life in Hours	W.P.C.	Average Total Life in Hours	W.P.C.	Average Total Life in Hours
40	2.56	600	2.71	900	2.89	1300
50	2.50	700	2.65	1000	2.81	1500
60	2.50	700	2.65	1000	2.81	1500
80	2.46	700	2.60	1000	2.78	1500
100	2.46	650	2.60	950	2.78	1400

of the gem metallized filament lamp. This lamp should not be confused with the metallic filament lamps, to be described later, because the material used is carbon, not a metal. As a result of special treatment the carbon filament assumes many of the characteristics of a metallic conductor, hence the term "metallized filament". The word "graphitized" has been proposed in place of metallized.

Preparation of Filament. When a filament, as treated in the ordinary manner, is run at a high temperature in a lamp, there is no improvement of the filament, but it was discovered that if the treated filaments were subjected to the extremely high temperature of the electric resistance furnace—3000 to 3700 degrees centigrade—at atmospheric pressure, the physical nature of the carbon was changed and the resulting filament could be operated at a higher temperature in the lamp and a higher efficiency, and still maintain a life comparable to that of a 3.1-watt lamp. This special heating of the filament, which is applied to the base filament before it is flashed, as well as to the treated filament, causes the cold resistance of the carbon to be very materially decreased and the filament, as used in the lamp, has a positive temperature coefficient—rise in resistance with rise in temperature—a desirable feature from the standpoint of voltage regulation of the circuit from which the lamps are operated. The high temperature also results in the driving off of considerable of the material which, in the ordinary lamp, causes the globe to blacken after the lamp has been in use for some time. The blackening of the bulb is responsible to a considerable degree for the decrease in candle-power of the incandescent lamp. The metallized filament lamp is operated at an efficiency of 2.5 watts per candle with a useful life of about 700 hours. The change in candle-power with the change in voltage is less than in the ordinary lamp on account of the positive temperature coefficient of the filament. These lamps are not manufactured for very low candle-powers, owing to the difficulty of treating very slender filaments, but they are made in sizes consuming from 40 to 250 watts. Table I gives some useful information in connection with metallized filament lamps. The filaments are made in a variety of shapes and the distribution curves are usually modified in practice by the use of shades and reflectors. The general appearance of the lamp does not differ from that of the ordinary carbon lamp.

METALLIC FILAMENT LAMPS

TANTALUM TYPE

Nature of Filament. The first of the metallic filament lamps to be introduced to any considerable extent commercially was the tantalum lamp. Dr. Bolton of the Siemens & Halske Company first discovered the methods of obtaining the pure metal tantalum. This metal is rendered ductile and drawn into slender filaments for incandescent lamps. Tantalum has a high tensile strength and a high melting point, and tantalum filaments are operated at temperatures much higher than those used with the carbon filament lamp. On account of the comparatively low specific resistance of this material the filaments for 110-volt lamps must be long and slender, and this necessitates a special form of support. Figs. 5, 6, and 7 show some interesting views of the tantalum lamp and the filament. This lamp is operated at the efficiency of 2 watts per candle-power, with a life comparable to that of the ordinary lamp. By special treatment it is possible to increase the resistance of the filaments so that they may be shorter and heavier than those used

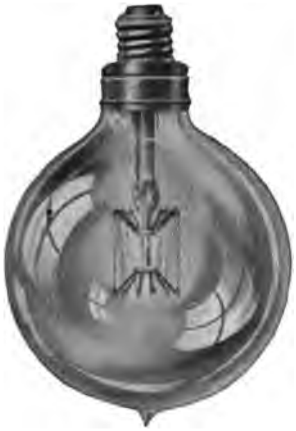


Fig. 5. Round Bulb Tantalum Lamp

in the first of the tantalum lamps. It should be noted that the life of this type of lamp on alternating-current circuits is somewhat uncertain; it is much more satisfactory for operation on direct-current circuits.

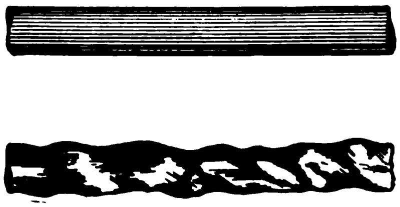


Fig. 6. Tantalum Filament Before and After One-Thousand Hours' Use

TUNGSTEN VACUUM TYPE

Early Methods of Preparing Filament. Following closely upon the development of the tantalum lamp came the tungsten lamp. Tungsten possesses a very high melting point. An indirect method was originally employed in forming filaments for incandescent lamps and there were several of these methods in use. In one method a fine carbon filament was flashed in an atmosphere of tungsten oxychloride mixed with just the proper proportion of hydrogen, in which case the filament gradually changed to one of tunsgten. A second method consisted of the use of powdered tungsten and some binding material, sometimes organic and in other cases metallic. The powdered tungsten was mixed with the binding material, the paste squirted into filaments, and the binding material was then expelled, usually by the aid of heat. Another method of manu-

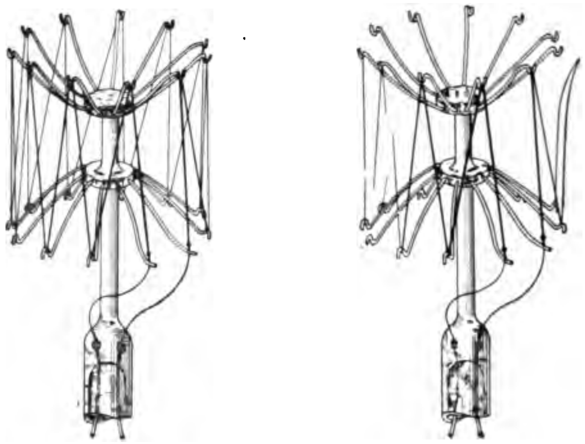


Fig. 7. Mounted Tantalum Filament Showing Appearance after Considerable Use and after Filament Has Disintegrated

facture consisted of securing tungsten in colloidal form, squirting it into filaments, and then changing them to the metallic form by passing electric current through them.

Difficulties in Providing Required Durability. Tungsten lamps, as formed by any of the above or similar processes, are extremely fragile, especially when cold, and the tungsten lamps in their early forms required very careful packing for shipment; were easily broken in ordinary service; could not be used satisfactorily where there was appreciable vibration; and there was a considerable reduction in candle-power with use, due to the blackening of the bulb. The first commercial tungsten lamps were produced in 1907, or thereabouts, and the development of the lamp has been continuous since that time. An efficiency of about 1.25 watts per candle-power was early realized for lamps of 100 watts rating or higher, and lamps consuming 40 and 60 watts were early available. In 1911 a process was developed for preparing tungsten in ductile form and wiredrawn filaments were made. These filaments proved to be much stronger than the filaments prepared by other processes but still further development has made the present wiredrawn filaments as much more rugged than the first drawn filaments as these were stronger than the filaments made by other processes.

Wiredrawn Filaments. In the first stages of development, wiredrawn filaments were prepared only with the very greatest difficulty but the wire can now be produced in any desired length and very uniform in cross section. The material for the filaments comes to the filament factory in the form of a concentrated tungsten ore from which tungstic oxide is obtained. This oxide is reduced by a special process requiring the agency of an electric furnace to produce tungsten metal in a powdered form. This tungsten metal is compressed into ingots about 6 inches long by one-fourth of an inch square and again heat-treated in an electric furnace, the effect of which treatment is to strengthen the ingot and make the material a good conductor of electricity. The material is then subjected to a temperature near the melting point in an atmosphere of hydrogen and the result of this treatment is to weld the tungsten particles firmly together. The ingot is then heated and swaged and the process repeated until it forms a rod about .03 inch in diameter and 30 feet long. This rod is hot drawn through special diamond dies and

TABLE II

Data on Standard Mazda Lamps

Voltage Range	Watts		Efficiency			Candle-Power	
	Rated	Actual	Rating	W.P.C.	Lumens per Watt	Mean Horiz'l	Mean Spherical
100 to 130	15	15.0	High	1.30	7.54	11.54	9.0
		14.6	Medium	1.35	7.26	10.80	8.4
		14.2	Low	1.40	7.00	10.15	7.9
	20	20.0	High	1.25	7.84	16.00	12.5
		19.5	Medium	1.30	7.54	15.04	11.7
		19.0	Low	1.34	7.31	14.20	11.1
	25	25.0	High	1.17	8.38	21.38	16.7
		24.25	Medium	1.22	8.03	19.96	15.6
		23.6	Low	1.27	7.72	18.55	14.5
	40	40.0	High	1.17	8.38	34.20	26.7
		38.9	Medium	1.22	8.03	32.00	25.0
		37.8	Low	1.27	7.72	30.00	23.4
	60	60.0	High	1.16	8.45	51.70	40.3
		58.3	Medium	1.21	8.10	48.40	37.7
		56.6	Low	1.26	7.78	45.00	35.1
	100	100.0	High	1.13	8.68	88.50	69.0
		97.2	Medium	1.18	8.30	82.40	64.2
		94.2	Low	1.23	7.97	77.10	60.1
	150	150.0	High	1.12	8.75	134.00	104.5
		146.0	Medium	1.17	8.38	125.00	97.5
		142.0	Low	1.22	8.03	116.00	90.5
	250	250.0	High	1.00	9.80	250.00	195.0
		244.0	Medium	1.04	9.42	234.00	182.5
		238.0	Low	1.08	9.07	220.50	172.0
200 to 260	25	25.0	Single	1.40	7.05	17.90	14.1
	40	40.0	Single	1.31	7.58	30.50	24.1
	60	60.0	Single	1.31	7.58	45.80	36.2
	100	100.0	Single	1.31	7.58	76.40	59.8
	150	150.0	Single	1.31	7.58	114.50	90.4
	250	250.0	Single	1.31	7.58	190.80	150.8

finally reduced to the desired size, the final drawings being made at lower temperatures or cold. Graphite is used as a lubricant during the process of drawing. The filament of a 10-watt 110-volt lamp is about .00075 inch in diameter, a remarkably fine wire. The balance of the manufacture of the tungsten lamp is not unlike that of the carbon incandescent lamp already described.

Improvements over Carbon Type. The modern tungsten lamp, in addition to the increased mechanical strength, shows improvements such as: the use of a chemical in the bulb to better the candle-power maintenance; a decrease in the size of the glass bulb and a complete standardization of bulb sizes; and the production of special forms of the filament, such as the helical form.

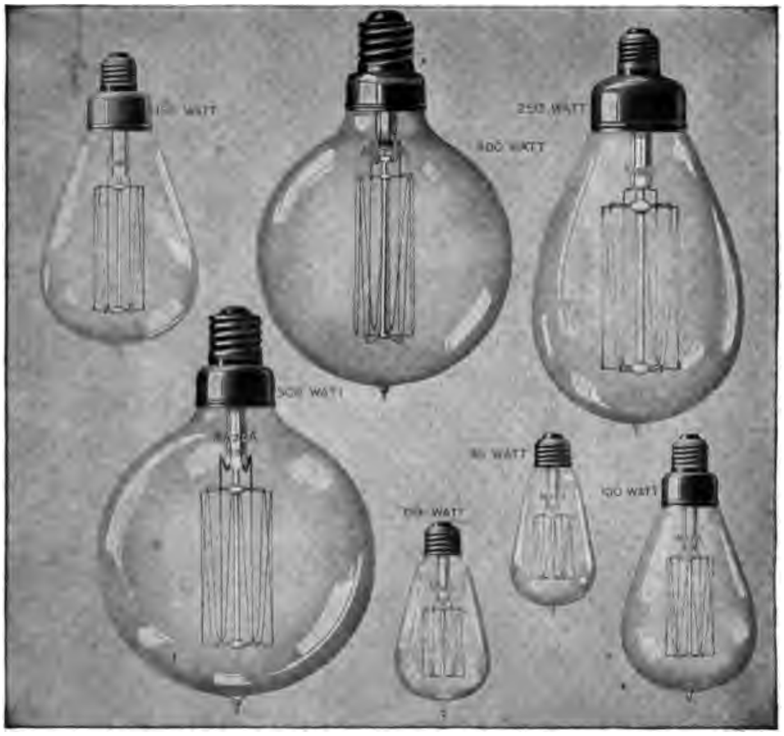


Fig. 8. Collection of Various Sizes of Mazda Lamps
Courtesy of National Electric Lamp Association

Table II gives useful data covering the regular Mazda lamp and Fig. 8 shows the appearance of these units.

In addition to lamps for 110- and 220-volt service the tungsten lamp forms a very desirable type of unit for series systems of street lighting. Still another field is that of low-voltage lamps for train lighting, sign lighting, automobiles, etc., and the tungsten filament is well adapted to miniature lamps which operate at low voltages.

In addition to the higher efficiency the tungsten lamp has still another advantage over the older carbon lamps in that the variation in candle-power with a change in voltage is not as great; hence poor voltage regulation of the distribution system is not so noticeable with the tungsten lamps. The curves in Fig. 9 show the relative behavior of the different types of filaments in this respect and indicate decidedly less change in candle-power for a given change in voltage for the tungsten lamp. Finally the light given by the tungsten filament, as used in the tungsten lamp, is whiter than that of any of the other filaments and hence is more desirable for most classes of illumination.

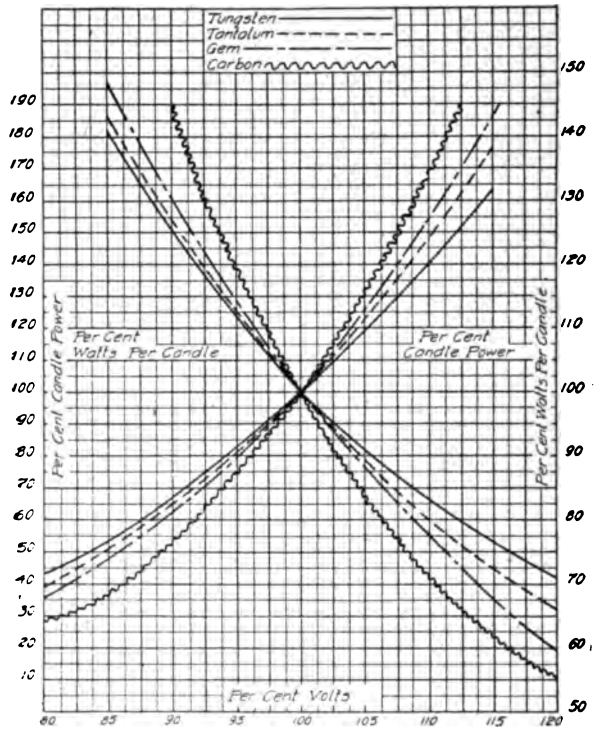


Fig. 9. Curve Showing Variation of Candle-Power and Watts per Candle Due to Change of Voltage

NITROGEN-FILLED TYPE

Characteristics and Efficiency. This lamp, Fig. 10, is the final word, at the present time, in the improvement of filament types of incandescent lamps and it is a recent improvement upon the tungsten lamp as ordinarily manufactured. One of the results of the continuous research, which has been carried on in connection with incandescent lamps, has been to show that if, instead of containing a high vacuum, the bulb of the tungsten lamp is filled with the inert gas nitrogen, at practically atmospheric pressure, and the filament then run at a very much higher temperature than had ordinarily been used with the vacuum type of lamp, the efficiency of the lamp could be improved and the life of the unit kept in the neighborhood of 1000 hours, the normal life rating of the regular incandescent units. So far, such lamps have been manufactured in very large units for the standard lighting circuits, rated at 750 and 1000 watts and giving an efficiency

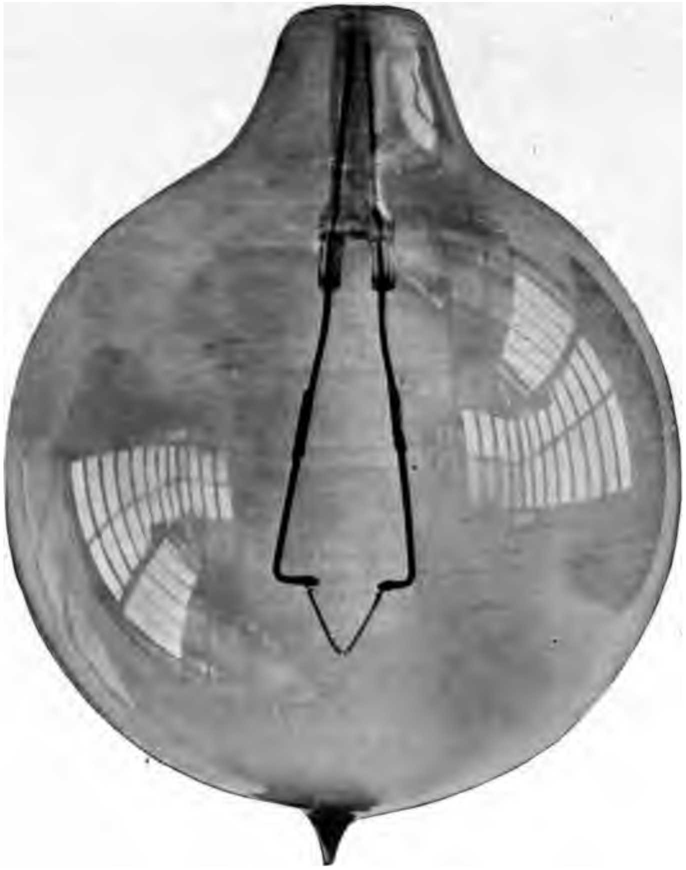


Fig. 10. Unmounted Nitrogen-Filled Lamp Showing Short Helical Filament

TABLE III

Tentative Data covering Nitrogen-Filled Mazda Lamps for Street Lighting Service on Series Circuits

(Rated Life—1350 hours)

CANDLE-POWER	AMPERES	WATTS PER CANDLE-POWER
80	6.6	.71
100	6.6	.70
250	6.6	.68
400	6.6	.66
600	6.6	.66
80	7.5	.71
250	7.5	.68
400	20.0	.5
600	20.0	.5
1000	20.0	.5

of .65 to .60 watts per candle-power; in sizes from 80 to 1000 candle-power for series lighting circuits and operating at efficiencies of from .71 to .5 watts per candle-power; and special lamps giving several thousand candle-power and operating at about .5 watts per candle-power.

It is expected that the development of this type of lamp will continue. At the present time lamps are only made with filaments of comparatively large cross section or filaments in rather tightly coiled helixes, Fig. 10; otherwise the appearance of the lamp is not different from that of the usual unit as manufactured for high candle-powers.

Table III gives tentative data on nitrogen-filled street-lighting units for series circuits.

The Just lamp, the Z lamp, the Osram lamp, the Zircon-Wolfram lamp, the Osmin lamp, etc., were all tungsten lamps, the filaments being prepared by some of the general methods already described, or modifications of them.

MISCELLANEOUS TYPES

Other Metallic Filament Lamps. Table IV gives the melting points of several metals which are highly refractory and those already mentioned are not the only ones which have been successfully used in incandescent lamps. Titanium, zirconium, iridium, etc., have

TABLE IV

Melting Point of Some Metals

Metal	Approximate Melting Point in Degrees Centigrade
Tungsten	3080–3200
Titanium	3000
Tantalum	2900
Osmium	2500
Platinum	1775
Zirconium	1500
Silicon	1200
Carbon (not a metal)	3000

been successfully employed, but tungsten lamps are the only ones which are used to any extent in the United States.

Nernst Lamp. The Nernst lamp is still another form of incandescent lamp, one type of which is shown in Fig. 11. The lamp is no longer manufactured but it was used quite extensively at one time and a brief description is given here.

Glower. This lamp used for the incandescent material certain oxides of the rare earths, the oxides being mixed in the form of a paste, then squirted through a die into a string which was subjected to a roasting process forming the filament or *glower* material of the lamp. The more recent glowers were made hollow instead of solid. The glowers were cut to the desired length and platinum terminals attached. The attachment of these terminals to the glowers was an important process in the manufacture of the lamp. The glowers were heated to incandescence in open air, a vacuum not being required.

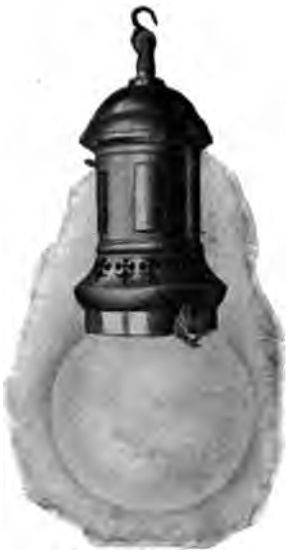


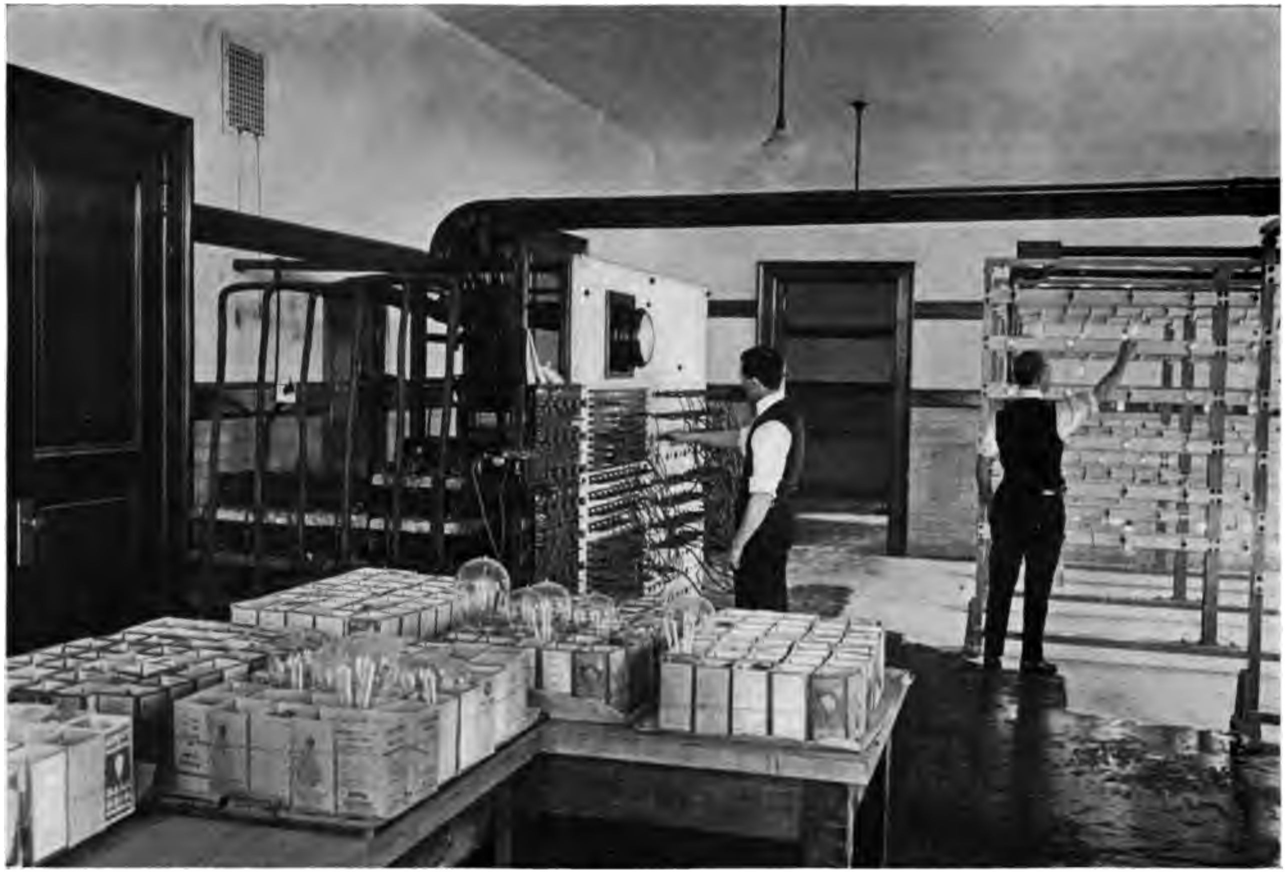
Fig. 11. Westinghouse Nernst Multiple-Glower Lamp

Heater. As the glower is a nonconductor when cold, some form of heater was necessary to bring it up to a temperature at which it would conduct. One form of heater consisted of a porcelain tube placed just above the glower, about which a fine platinum wire was wound; the wire was coated with a cement. Two or more of these tubes were mounted directly over the glower, or glowers, and served as a reflector as well as a heater.

The heating device was connected across the circuit when the lamp was first turned on, and it had to be cut out of circuit after the glowers became conductors in order to save the energy consumed by the heater and to prolong the life of the heater. The automatic cut-out was operated by means of an electromagnet so arranged that current flowed through this magnet as soon as the glower became a conductor, and contacts in the heater circuit were opened by this magnet. The contacts in the heater circuit were kept normally closed, usually by the force of gravity.

Ballast. The conductivity of the glower increased with the increase of temperature—the material has a negative temperature coefficient; hence, if it were used on a constant potential circuit directly, the current and temperature would continue to rise until the glower was destroyed. To prevent the current from increasing beyond the desired value, a ballast resistance was used in series with the glower. As is well known, the resistance of iron wire increases rapidly with increase in temperature, and the resistance of a fine pure iron wire was so adjusted that the resistance of the combined circuit of the glower and the ballast became constant at the desired temperature of the glower. The iron wire had to be protected from the air to prevent oxidization and too rapid temperature changes and, for this reason, it was mounted in a glass bulb filled with hydrogen. Hydrogen was selected for this purpose because it is an inert gas and conducts the heat from the ballast to the walls of the bulb better than other gases which might be used.

Advantages Claimed. All of the parts enumerated, namely, glower, heater, cut-out, and ballast, were mounted in a suitable manner; the smaller lamps with but one glower were arranged to fit in an incandescent lamp socket, while the larger types were constructed with as many as four glowers and were arranged to be supported in special fixtures, like small arc lamps. All parts were mechanically arranged so that renewals might easily be made when necessary and it was not possible to insert a part belonging to one type of lamp into a lamp of a different type.



LAMP TESTING ROOM, NATIONAL BUREAU OF STANDARDS
Copyright by Waldon Fawcett

The advantages claimed for the Nernst lamp were: high efficiency; a good color of light; a good distribution of light without the use of reflectors; a long life with low cost of maintenance; and a complete series of units, thus allowing its adaption to practically all classes of illumination.

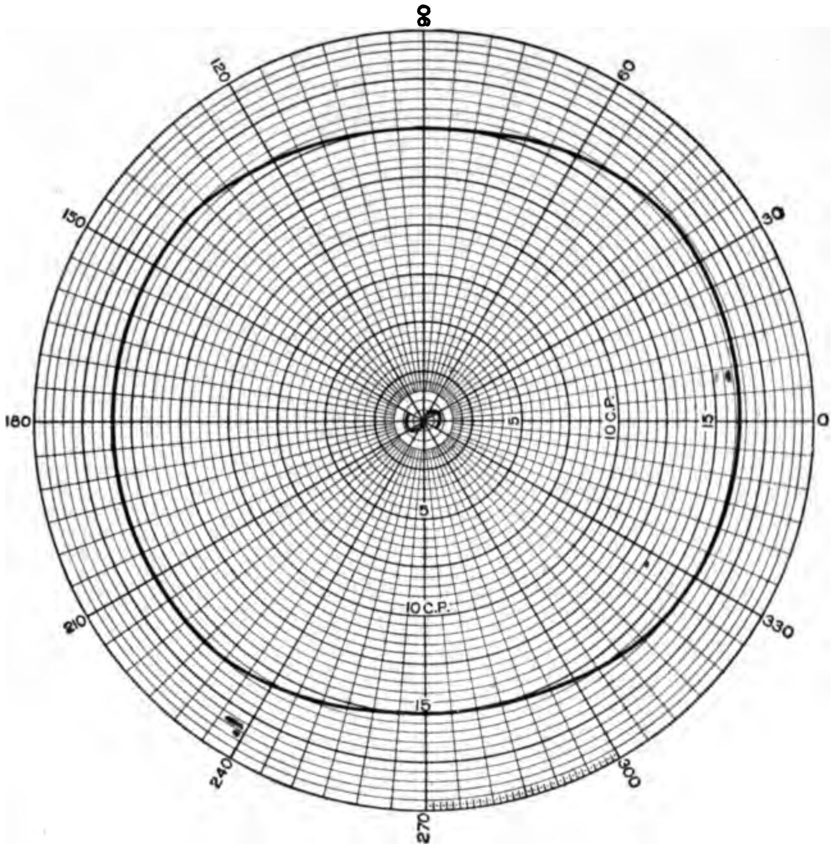


Fig. 12. Horizontal Distribution Curve for Single-Loop Carbon Filament

Nernst lamps were made for 110- and 220-volt service and in sizes from 66 to 528 watts, giving a mean candle-power below the horizontal of from 50 to 500 and an efficiency of from 1.38 to 1.09 watts per mean hemispherical candle-power.

DISTRIBUTION CURVES

Nature and Value. By a distribution curve for any type of lamp is meant a curve showing the value of the light given by the lamp in different directions. Usually these curves take the form of vertical distribution curves in which the light given in the different directions throughout 360 degrees in a vertical plane are given and a horizontal distribution curve in which the light given in different directions throughout 360 degrees in a horizontal plane are given. The mean of the values of the candle-power in a horizontal plane gives the mean horizontal candle-power, while a mean of the values in the vertical plane gives the mean vertical candle-power of the

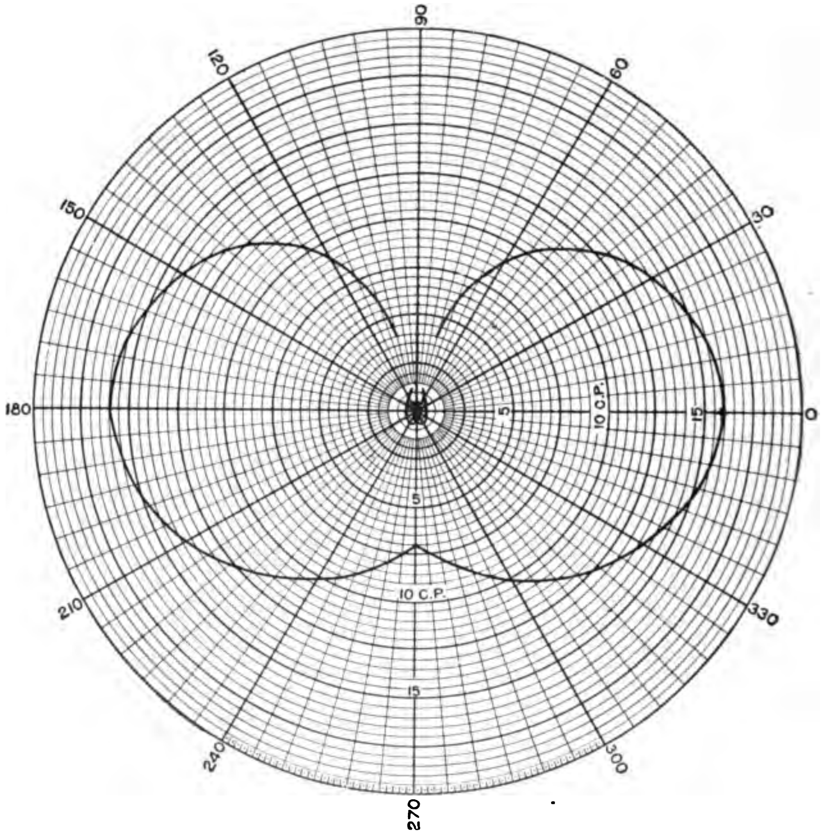


Fig. 13. Vertical Distribution Curve for Single-Loop Carbon Filament

light source. In the absence of more specific statements the candle-power of a lamp is taken to be the mean *horizontal* candle-power.

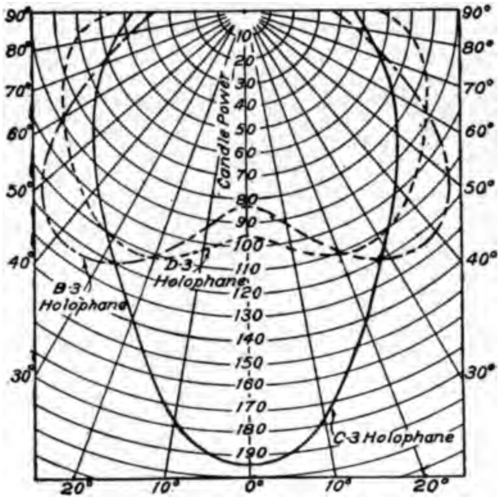


Fig. 14. C. P. Distribution Curves of 100-Watt G. E. Tungsten Lamps with B-3, C-3, and D-3 Holophane Reflectors

The use of shades and reflectors greatly modifies the form of the distribution curves of lamps, the exact nature of the modification depending upon the design of the shade or the reflector. Since lamps are almost always used with some type of shade or reflector, the distribution curves of the bare lamps have their greatest usefulness for comparative purposes. The distribution curves of the lamps with the reflectors are of direct use in calculations of illum-

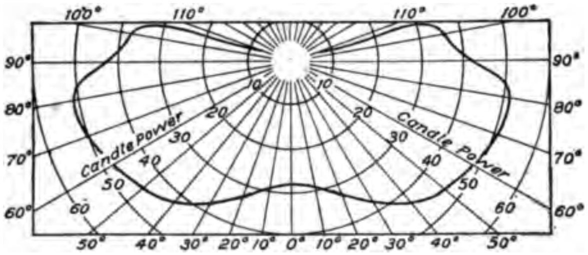


Fig. 15. C. P. Distribution Curve for 40-C. P., G. E. Tungsten Series Lamp with Radial Wave Reflector

ination. Figs. 12 to 19 inclusive are typical of the distribution curves of incandescent lamp units.

Mean Spherical Candle-Power. When comparing lamps which give an entirely different light distribution, the mean horizontal candle-power does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used

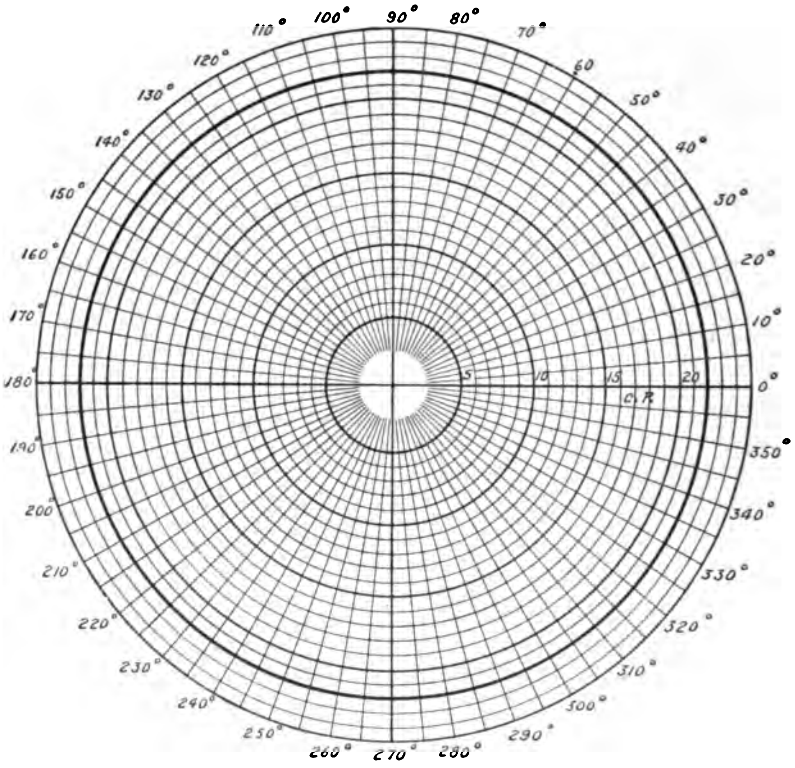


Fig. 16. Horizontal Distribution Curve of a Mazda Lamp

instead. By mean spherical candle-power is meant a mean value of the light taken in all directions. The methods for determining this will be taken up under "Photometry". The mean hemispherical candle-power has reference, usually, to the light given out below the horizontal plane. The *spherical reduction factor* for the ordinary tungsten lamp is from .78 to .79.

SPECIAL VAPOR LAMPS

STANDARD MERCURY VAPOR LAMP

Operating Principles. The mercury vapor lamp in this country is put on the market by the Cooper-Hewitt Electric Company and it is being used to a considerable extent for industrial illumination.

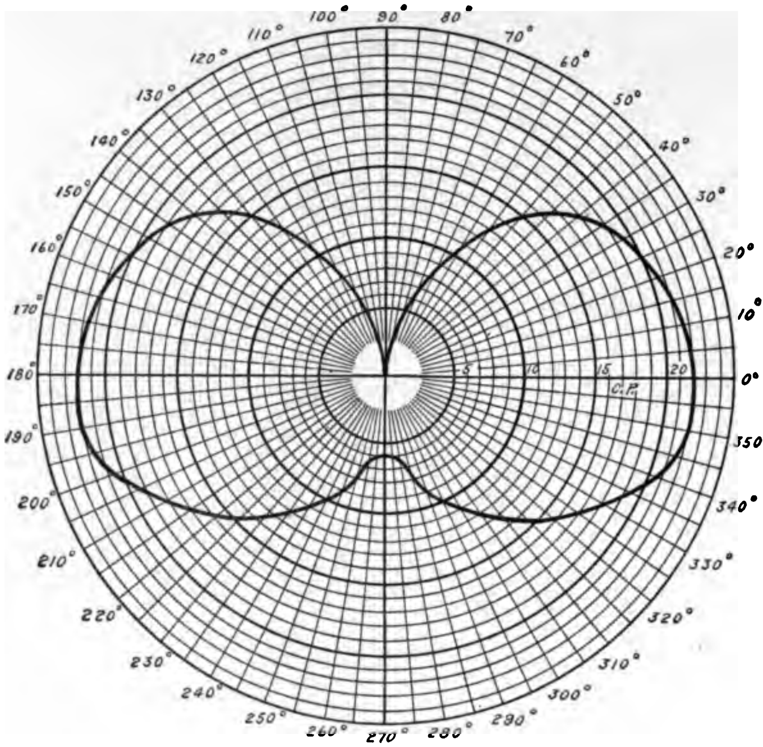


Fig. 17. Vertical Distribution Curve of a Mazda Lamp

In this lamp mercury vapor, rendered incandescent by the passage of an electric current through it, is the source of light. In its standard form this lamp consists of a long glass tube from which the air has been carefully exhausted and which contains a small amount of metallic mercury. The mercury is held in a large bulb at one end of the tube and forms the negative electrode in the direct-current lamp. The other electrode is formed by an iron cup and ination. Figs. 12 to 19 inclusive are typical of the distribution curves of incandescent lamp units.

Mean Spherical Candle-Power. When comparing lamps which give an entirely different light distribution, the mean horizontal candle-power does not form a proper basis for such comparison, and the mean spherical or the mean hemispherical candle-power is used

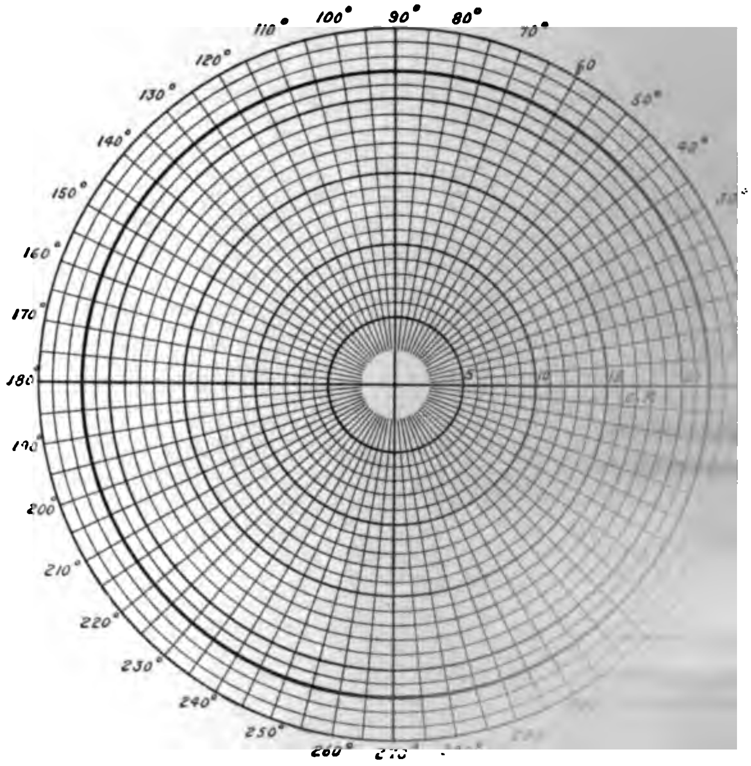


Fig. 16. Horizontal Dist

instead. By mean spherical
of the light taken in all dir
this will be taken up under
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the horizontal plane. Th
tungsten lamp is from .7

formed. The tilting method of starting is preferred and this tilting is brought about automatically in the more recent types of lamp. Fig. 19 shows the connections for starting automatically two lamps in series. A steadying resistance and reactance are connected as shown in this figure.

Applications. The mercury vapor lamp is constructed in rather large units, the 55-volt, 3.5-ampere lamp being the smallest standard size. The color of the light emitted is objectionable for some purposes as there is an entire absence of red rays, in fact, the light is practically monochromatic. The illumination from this type of lamp is excellent where sharp contrast or minute detail is to be brought out and this fact has led to its introduction for such classes of lighting as silk mills and cotton mills. On account of its color, the application of this lamp is limited to the lighting of shops, offices, and drafting rooms, or to display windows where the goods shown will not be changed in appearance by the color of the light. It is used to a considerable extent in photographic work on account of the chemical properties of the light. Special reactances must be provided for a mercury arc lamp operating on single-phase alternating-current circuits. These alternating-current lamps have practically the same efficiency as the direct-current lamps.

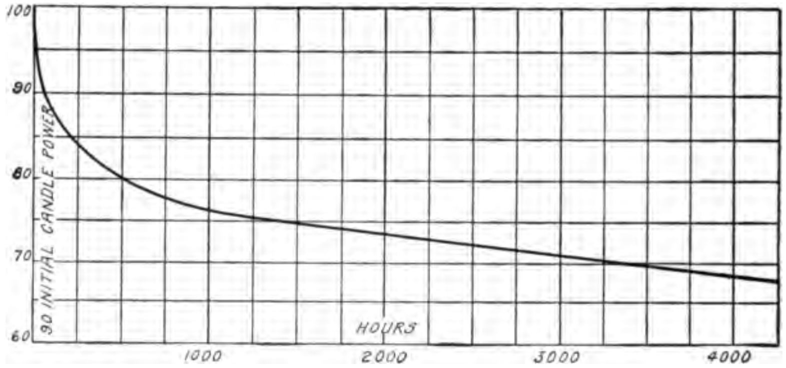


Fig. 21. Candle-Power Performance of Two 21-Inch, 55-Volt 3.3-Ampere Mercury Vapor Lamps

The distribution of light about a plane taken at right angles to the tube of a Cooper-Hewitt lamp is shown in Fig. 20. The change in candle-power with use is illustrated in Fig. 21.

QUARTZ MERCURY VAPOR LAMP

Comparison with Ordinary Mercury Lamp. *Increase in Voltage and Temperature.* Since in the mercury vapor lamp the arc at the electrode gives practically no light but consumes some energy and the bulk of the light is given by the mercury vapor column, the efficiency of the mercury vapor tube as a light giving source is improved by using very long tubes, as in the standard lamp; or the performance may be improved by using a higher voltage per unit length of the tube than is ordinarily employed, provided a tube can be made to withstand the higher temperatures reached with this higher voltage per unit length. The vapor pressure is low in the regular glass tube, seldom over one-eighth inch of mercury pressure, but if the tubes are made of quartz, which is capable of standing a much higher temperature than ordinary glass, the drop in potential per inch of tube length can be increased to 30 or more times that allowable with glass tubes.

White Color of Light. When operated in this manner the mercury vapor actually becomes incandescent and the character of the light given by the lamp is changed, red and orange rays being added to the yellow, blue, green, and violet of the ordinary mercury vapor lamp. The pioneer work on this type of lamp was done in Germany but it has since been taken up in the United States and the lamp has been developed into a commercial form.

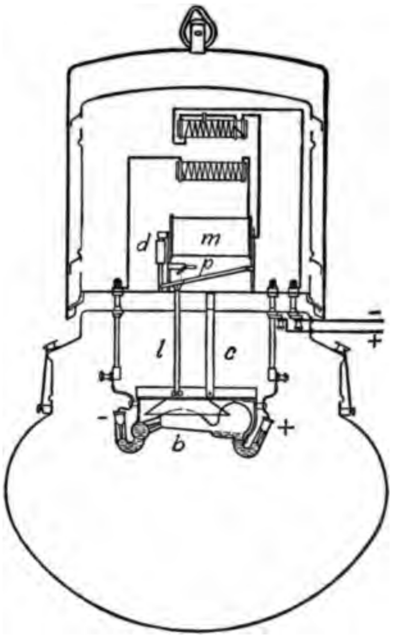


Fig. 22. Diagram of 110-Volt 3.8-Ampere Cooper-Hewitt Quartz Lamp

Construction and Operation. The light-giving element of the commercial lamp is a short tube of quartz containing mercury vapor. The necessary mechanism for starting and controlling the lamp is placed in a hood above the quartz tube and the tube itself is sur-

TABLE V

Data on Quartz Tube Lamps

(Cooper-Hewitt)

Volts, Nominal	Current, Average	Candle-Power Mean Hemispherical With Clear Glass Globe	Watts per Mean Hemispherical Candle-Power
110	3.8	1000	0.42
220	3.3	2400	0.30
550	2.0	3500	0.31

rounded by a glass globe, partly for the purpose of cutting off the ultra-violet light given by the mercury vapor and not screened off by the quartz tube. The details of a Cooper-Hewitt quartz lamp are illustrated in Fig. 22 and the general appearance of one of these lamps is shown in Fig. 23. Referring to Fig. 22, which illustrates the mechanism of a 110-volt 3.8-ampere direct-current lamp: *b* is the quartz tube or burner placed in a suitable holder which is pivoted in a support c and attached to the lever *l*; *l* is linked to the movable iron armature *m*; *d* is a dashpot; *p* is a small permanent magnet installed for the purpose of locking the mechanism and preventing its operation, if the lamp should be connected in to the circuit with a wrong polarity. Closing the lamp switch automatically tips the quartz tube and starts the lamp in operation. Table V gives some operating data for the Cooper-Hewitt quartz lamp.

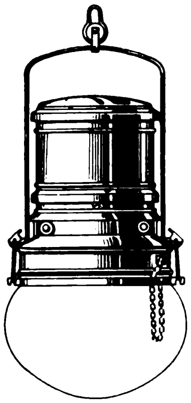


Fig. 23. Standard Cooper-Hewitt Quartz Lamp

TUBE LIGHTING

Moore Tube Light. *Use of Geissler Tube Principle.* The Moore light makes use of the familiar Geissler tube discharge—discharge of electricity through a vacuum tube—as a source of illumination. The practical application of this discharge to a system of lighting has involved a large amount of consistent research on the part of the inventor and it has now been brought to such a stage that several installations have been made. The system, while probably not destined to have any extended commercial use, has many interesting features.

Method of Installation. In the normal method of installation, a glass tube 1¾ inches in diameter is made up by connecting standard lengths of glass tubing together until the total desired length is reached and this continuous tube, which forms the source of light when in operation, is mounted in the desired position with respect to the plane of illumination. In many cases the tube forms a large rectangle mounted just beneath the ceiling of the room to be lighted. The tube may be of any reasonable length, actual values running from 40 to 220 feet. In order to provide an electrical discharge through this tube it is customary to lead both ends of the tube to the high tension terminals of a transformer, Fig. 24, the low tension side of which may be connected to the alternating-current lighting mains. This transformer is constructed so that the high tension terminals are not exposed and the current is led into the tube by means of platinum wires attached to carbon electrodes. The electrodes are about 8 inches in length. The ends of the tube and the high tension terminals are enclosed in a steel casing so as effectually to prevent anything from coming in contact with the high potential of the system. As stated, the low tension side of the transformer is connected to the usual 60-cycle lighting mains. If direct current is used for distribution, a motor-generator set for furnishing alternating current to the primary of the transformer is required. Any frequency from 60 cycles up is suitable for the operation of these tubes. At lower frequencies there is some appreciable variation of the light emitted.

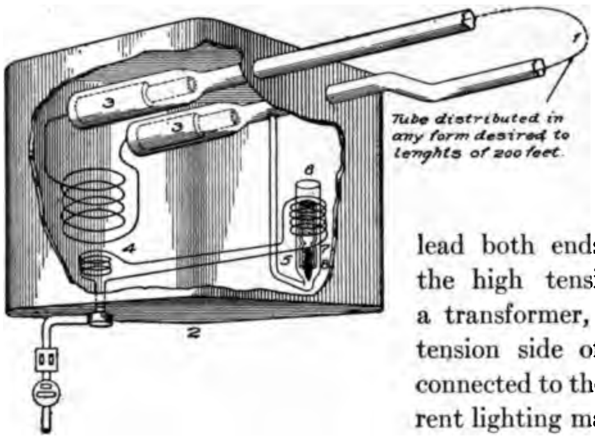

1
Tube distributed in any form desired to lenghts of 200 feet.
3
3
8
4
5
7
6
2

Fig. 24. Diagram Showing Essential Features of Moore Light. *1*-Lighting Tube; *2*-Transformer Case; *3*-Lamp Terminals; *4*-Transformer; *5*-,*6*-,*7*-, *8*-Regulators

Color of Light. The color of the light emitted by the tube depends upon the gas used in it. The regulator is fitted with some chemical arrangement whereby the proper gas is admitted to it when

TABLE VI

Data on the Moore Tube Light

Length of Tube	Transformer Capacity	Power Factor of Circuit	Voltage at Lamp Terminals
40–70 ft.	2 kw.	65–84%	3146 for 40-ft. tube, at 12 hefners per ft.
80–125 "	2.75 "		
130–180 "	3.5 "		
190–220 "	4.5 "		12,441 for 220-ft. tube, at 12 hefners per ft.

the tube is in operation. The tube gives the highest efficiency when nitrogen is employed and the light emitted when this gas is used is yellowish in color. Air gives a pink appearance to the tube and carbon dioxide is employed when a white light is desired.

Advantages Claimed. Table VI gives general data on the Moore tube light. The advantages claimed for this light are: high efficiency, good color, and low intrinsic brilliancy.

Pressure in tube, about $\frac{1}{10}$ mm. of mercury.
Watts per hefner, 3.2 for 20-foot tube including transformer.
Watts per hefner, 1.4 for 180-foot tube including transformer.
Hefner per foot, normal, 12.
Note that one hefner equals 0.88 candle-power.

Neon Tube Light. *Characteristics and Advantages of Method.* Neon, a rare gas of which the atmosphere contains about one part in 66,000, can be obtained as a by-product of the manufacture of oxygen from the air and it may be used in connection with tube lighting in a manner similar to the way in which nitrogen is used in the Moore lamp. When used in this manner it must be in a very pure state. Lamps have been manufactured for the use of neon, with the following general characteristics:

Tubes 6 meters long have a life comparable to that of incandescent lamp units, namely 1000 hours, or more.

The necessary potential is about one-third that required for a similar Moore tube—about 800 volts for a tube 6 meters long.

The neon tube gives about 200 candle-power per meter of length as against about 60 candle-power for a nitrogen tube.

An efficiency of 0.5 watts per candle is claimed for the neon tube.

Color of Light. The color of the light, unmodified, is too red for ordinary illumination. To improve this, correcting tubes containing mercury have been added to some lamps and, by the use of such correcting tubes, the color has been greatly improved but the efficiency of the unit is reduced so that about 0.8 watt per candlepower is required for their operation.

Small tubes for display lighting have been manufactured but it is not at all likely that neon tubes, in their present state of development, will have any great commercial application, even though they have some very desirable characteristics.

CARBON ARC LAMPS

ORDINARY OPEN AND ENCLOSED ARC TYPES

Principles of the Electric Arc. Suppose two carbon rods are connected in an electric circuit and the circuit is closed by touching the tips of these rods together; on separating the carbons again the circuit will not be broken, provided the space between the carbons be not too great, but will be maintained through the arc formed at these points. This phenomenon, which is the basis of the arc light, was first observed on a large scale by Sir Humphrey Davy, who used a battery of 2000 cells and produced an arc between charcoal points 4 inches apart.

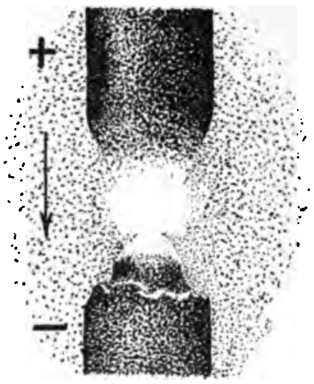


Fig. 25. Electric Arc Between Carbon Terminals

Nature of Arc. As the incandescence of the carbons across which an arc is maintained, together with the arc itself, forms the source of light for a large portion of arc lamps, it will be well to study the nature of the arc. Fig. 25 shows the general appearance of an arc between two carbon electrodes when maintained by direct-current.

Action of Current on Carbons. Here the current is assumed as passing from the top carbon to the bottom one as indicated by the arrow and signs. We find, in the direct-current arc, that most of the light issues from the tip of the positive carbon, or electrode, and this portion is known as the "crater" of the arc. This crater has a temperature of from 3000 to 3500 degrees centigrade, the temperature at which the carbon vaporizes, and it gives from 80 to 85 per cent of the light furnished by the arc. The negative carbon becomes pointed at the same time that the positive one is hollowed out to form the crater and it is also incandescent but not to as great a degree as the positive carbon. Between the electrodes there is a band of violet light, the arc proper, and this is surrounded by a luminous zone of a golden yellow color. The arc proper does not furnish more than 5 per cent of the light emitted when pure carbon electrodes are used.

The carbons are worn away or consumed by the passage of the current, the positive carbon being consumed about twice as rapidly as the negative.

Preparation of Carbons. Carbons are either molded or forced from a product known as "petroleum coke" or from similar materials, such as lampblack. The material is thoroughly dried by heating to a high temperature; then it is ground to a fine powder and combined with some substance such as pitch which binds the fine particles of carbon together. After this mixture is again ground, it is ready for molding. The powder is put in steel molds and heated until it takes the form of a paste, when the necessary pressure is applied to the molds. For the forced carbons, the powder is formed into cylinders which are placed in machines that force the material through a die so arranged as to give the desired diameter. The forced carbons are often made with a core of some special material, this core being added after the carbon proper has been finished. The carbons, whether molded or forced, must be carefully baked to drive off all volatile matter. The forced carbon is always more uniform in quality and cross section and is the type of carbon which must be used in the carbon-feed lamp. The adding of a core of a

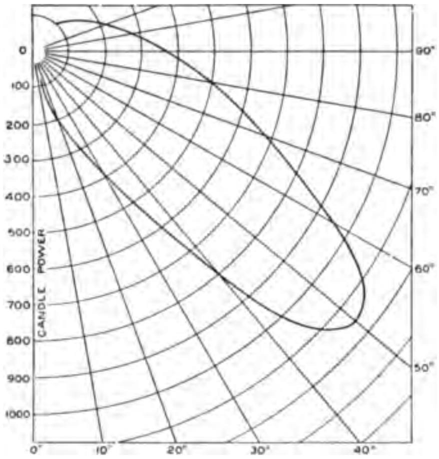


Fig. 26. Distribution Curve for D. C. Arc Lamp in Vertical Plane

different material seems to change the quality of light and, being more readily volatilized, keeps the arc from wandering.

Plating of carbons with copper is sometimes resorted to for molded forms for the purpose of increasing the conductivity and, by protecting the carbon near the arc, prolonging the life.

Distribution Curve. The light distribution curve of a direct-current arc, taken in a vertical plane, is shown in Fig. 26. Here it is seen that the maximum amount of light is given off at an angle of about 50 degrees from the vertical, the negative carbon shutting off the rays of light that are thrown directly downward from the crater.

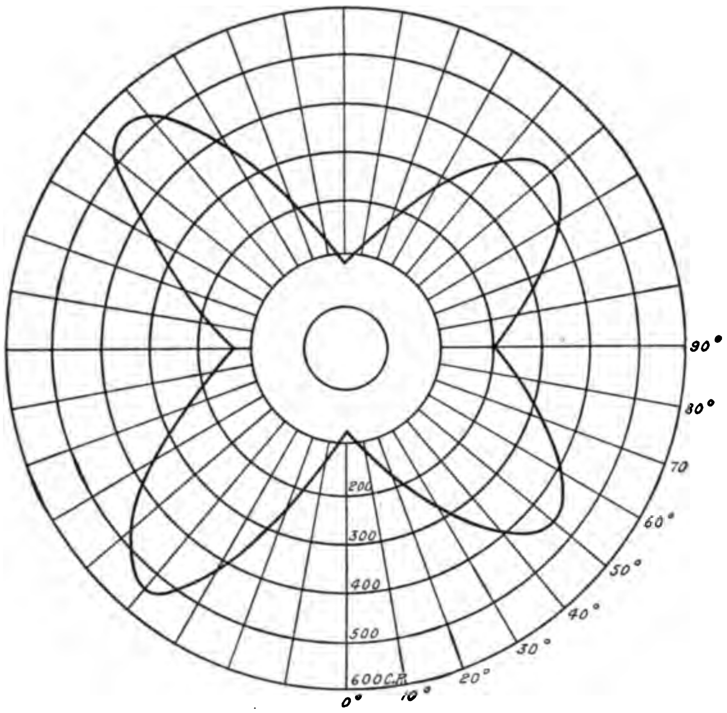


Fig. 27. Distribution Curve for A. C. Arc Lamp in Vertical Plane

If alternating current is used, the upper carbon becomes positive and negative alternately and there is no chance for a crater to be formed, both carbons giving off the same amount of light and being consumed at about the same rate. The light distribution curve of an alternating-current arc is shown in Fig. 27.

CARBON FEED MECHANISMS

In a practical lamp we must have not only a pair of carbons for producing the arc, but also means for supporting these carbons, together with suitable arrangements for leading the current to them and for maintaining them at the proper distance apart. The carbons are kept at the proper distance apart by the operating mechanisms which must perform the following functions:

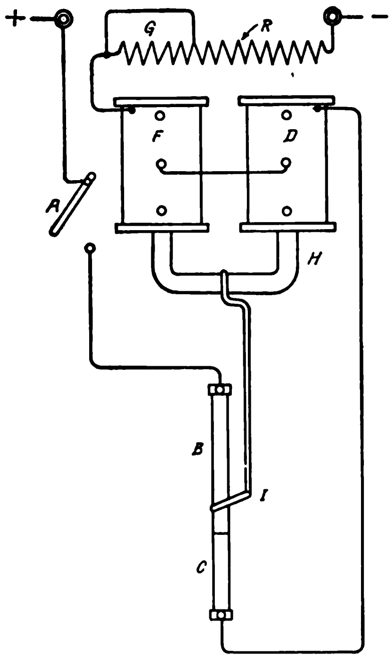


Fig. 28. Series Mechanism for D. C. Arc Lamp

(1) The carbons must be in contact, or be brought into contact, to start the arc when the current first flows.

(2) They must be separated immediately afterward at the right distance to form a proper arc.

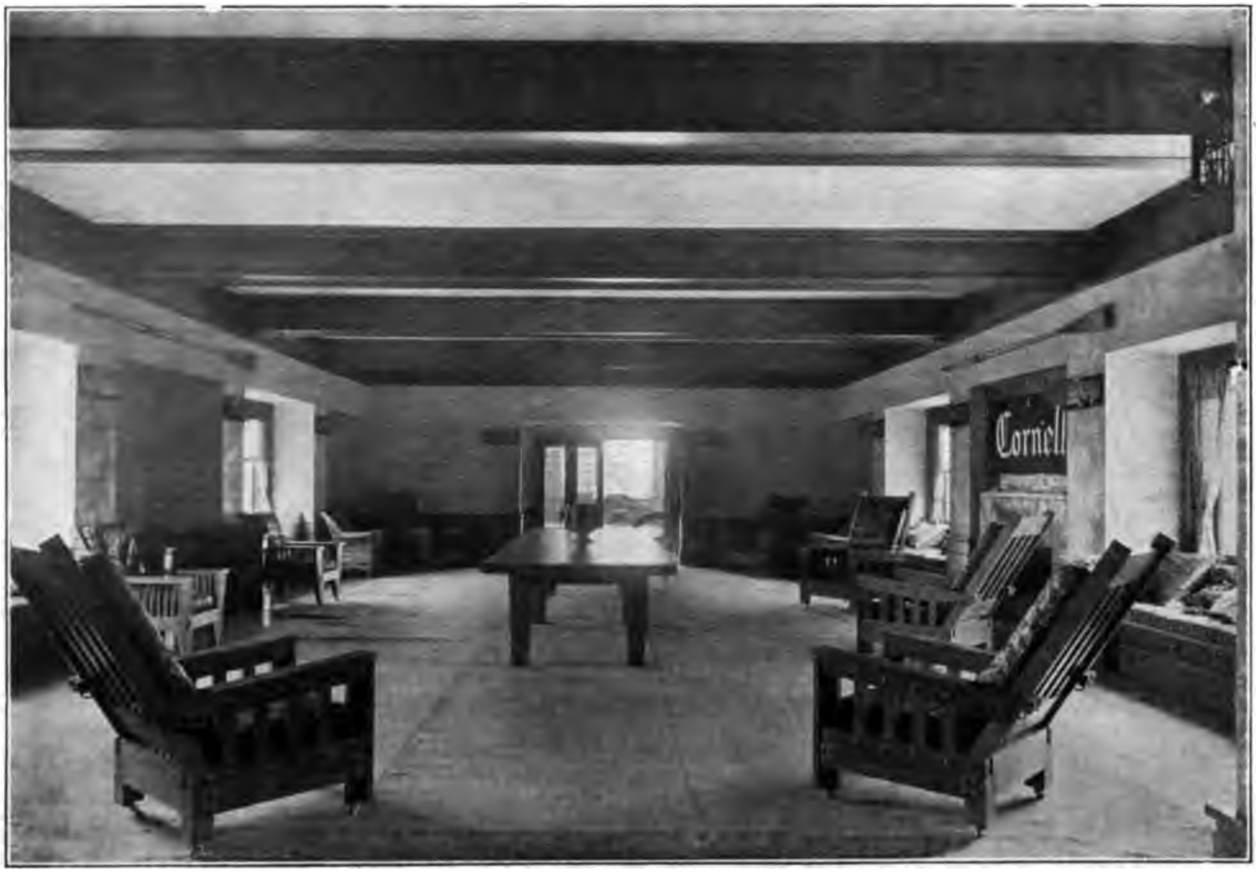
(3) The carbons must be fed to the arc as they are consumed.

(4) The circuit should be open or closed when the carbons are entirely consumed, depending on the method of power distribution.

The feeding of the carbons may be done by hand, as is the case in some stereopticons using an arc, but for ordinary illumination the striking and maintaining of the arc must be automatic. It is made so in all cases by means of solenoids acting against the force of gravity or against springs. There are an endless number of such mechanisms, but a few only will be described here. They may be roughly divided into three classes: shunt, series, and differential mechanisms.

Shunt Mechanism. In shunt lamps, the carbons are held apart before the current is turned on and the circuit is closed through a solenoid connected in across the gap so formed. All of the current must pass through this coil at first and the plunger of the solenoid is arranged to draw the carbons together, thus starting the arc. The pull of the solenoid and that of the springs are adjusted to maintain the arc at its proper length.

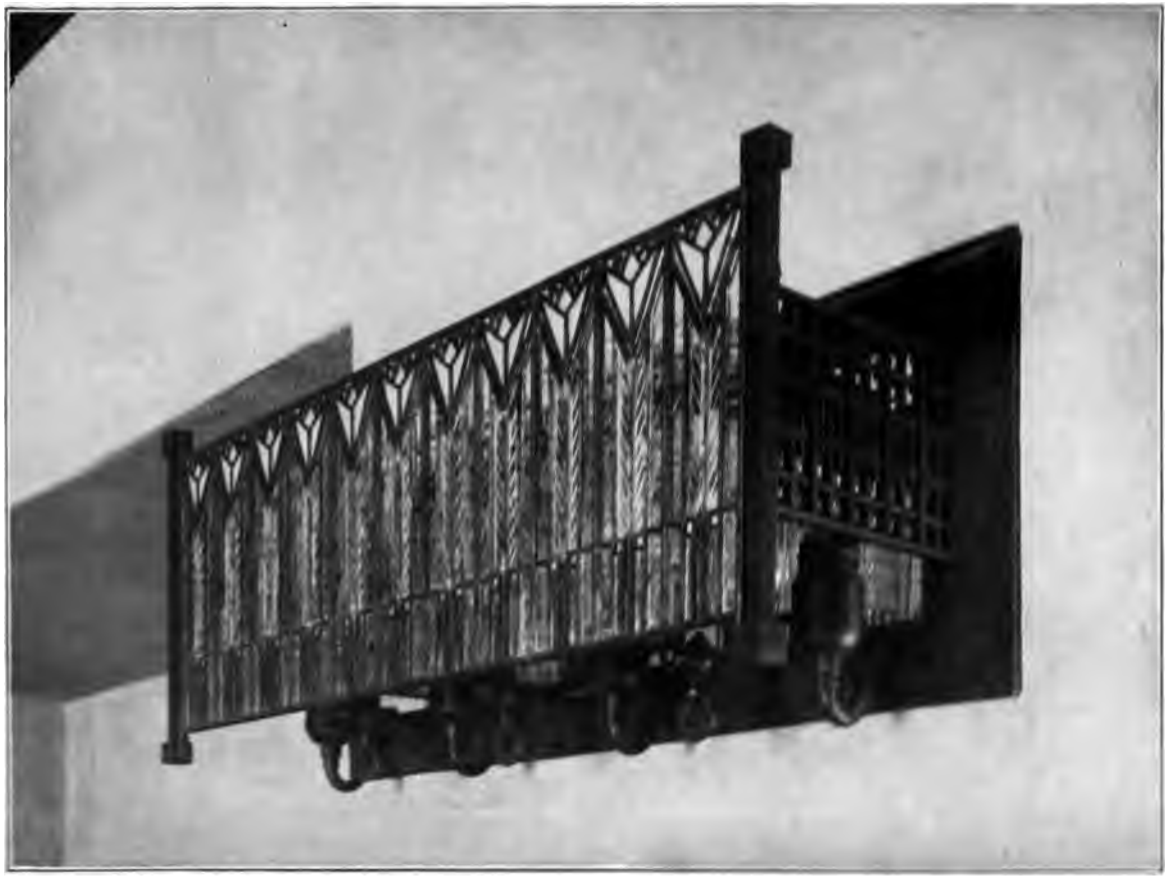
Such lamps have the disadvantage of a high resistance at the



LIVING ROOM IN ALPHA DELTA PHI CHAPTER-HOUSE AT CORNELL UNIVERSITY, ITHACA, NEW YORK

Dean and Dean, Architects, Chicago, Illinois

Oak stained a grey green and waxed; furniture to match; plaster stained and waxed. For exterior and plans see pages 58, 122, and 139, Volume II. For other interiors see page 330, this volume



GAS AND ELECTRIC FIXTURE IN LIVING ROOM OF ALPHA DELTA PHI CHAPTER-HOUSE AT CORNELL UNIVERSITY, ITHACA, N. Y.

Dean & Dean, Architects, Chicago, Ill.

Corrugated Mirror in the Iron Frame; Iron Brackets and Leaded Glass Screen.

start—450 ohms or more—and are difficult to start on series circuits, on account of the high voltage required. They tend to maintain a constant voltage at the arc, but do not aid the dynamo in its regulation, so that the arcs are liable to be a little unsteady.

Series Mechanism. With the series-lamp mechanism, the carbons are together when the lamp is first started and the current, flowing in the series coil, separates the electrodes, striking the arc. When the arc is too long, the resistance is increased and the current is lowered so that the pull of the solenoid is weakened and the carbons feed together. This type of lamp can be used only on constant-potential systems.

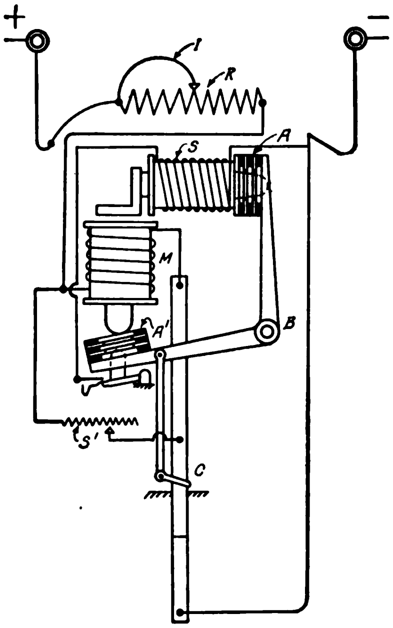


Fig. 29. Differential Mechanism for D. C. Arc Lamp

Fig. 28 shows a diagram of the connection of such a lamp. This diagram is illustrative of the connection of one of the lamps manufactured by the Western Electric Company, for use on a direct-current constant-potential system. The symbols + and − refer to the terminals of the lamp and the lamp must be so connected that the current flows from the top carbon to the bottom one. *R* is a series resistance, adjustable for different voltages by means of the shunt *G*. *F* and *D* are the controlling solenoids connected in series with the arc. *B* and *C* are the positive and negative carbons respectively, while *A* is the switch for turning the current on and off. *H* is the plunger of the solenoids and *I* is the carbon clutch, this being what is known as a "carbon-feed lamp". The carbons are together when *A* is first closed; the current is excessive; and the plunger is drawn up into the solenoids, lifting the carbon *B* until the resistance of the arc lowers the current to such a value that the pull of the solenoid just counterbalances the weight of the plunger and carbon. G must be so adjusted that this point is reached when the arc is at its normal length.

Differential Mechanism. In the differential lamp, the series and shunt mechanisms are combined, the carbons being together at the start and the series coil arranged so as to separate them; while the shunt coil is connected across the arc, as before, to prevent the carbons from being drawn too far apart. This lamp operates only over a low-current range but it tends to aid the generator in its regulation.

Fig. 29 shows a lamp having a differential control, this also being the diagram of a Western Electric Company arc lamp for a direct-current constant-potential system. Here S represents the shunt coil and M the series coil, the armature of the two magnets A and A' being attached to a bell-crank, pivoted at B, and attached to the carbon clutch C. The pull of coil S tends to lower the carbon while that of M raises the carbon and the two are so adjusted that equilibrium is reached when the arc is of the proper length. All of the lamps are fitted with an air dashpot, or some damping device, to prevent too rapid movement of the working parts.

TYPES

Classification. Arc lamps are constructed to operate on direct-current or alternating-current systems when connected in series or in multiple. They are also made in both the open and the enclosed forms.

By an *open arc* is meant an arc lamp in which the arc is exposed to the atmosphere, while in the *enclosed arc* an inner or enclosing globe surrounds the arc and this globe is covered with a cap which renders it nearly air-tight. Fig. 30 is a good example of an enclosed arc as manufactured by the General Electric Company.

Direct-Current Arcs. *Open Type.* Open arcs for direct-current systems were the first to be used to any great extent. When used they are always connected in series and are run from some form of special arc machine, a description of which may be found in any book dealing with types of generators.

Each lamp requires in the neighborhood of 50 volts for its operation and, since the lamps are connected in series, the voltage of the system will depend on the number of lamps; therefore, the number of lamps that may be connected to one machine is limited by the maximum allowable voltage on that machine. By special construction as many as 125 lamps are run from one machine but even this size of generator is not as efficient as one of greater capacity. Such generators are usually wound for 6.6 or 9.6 amperes. Since the carbons are exposed to the air at the arc, they are rapidly consumed, requiring that they be renewed daily for this type of lamp. The open arc lamp is used but little at present.

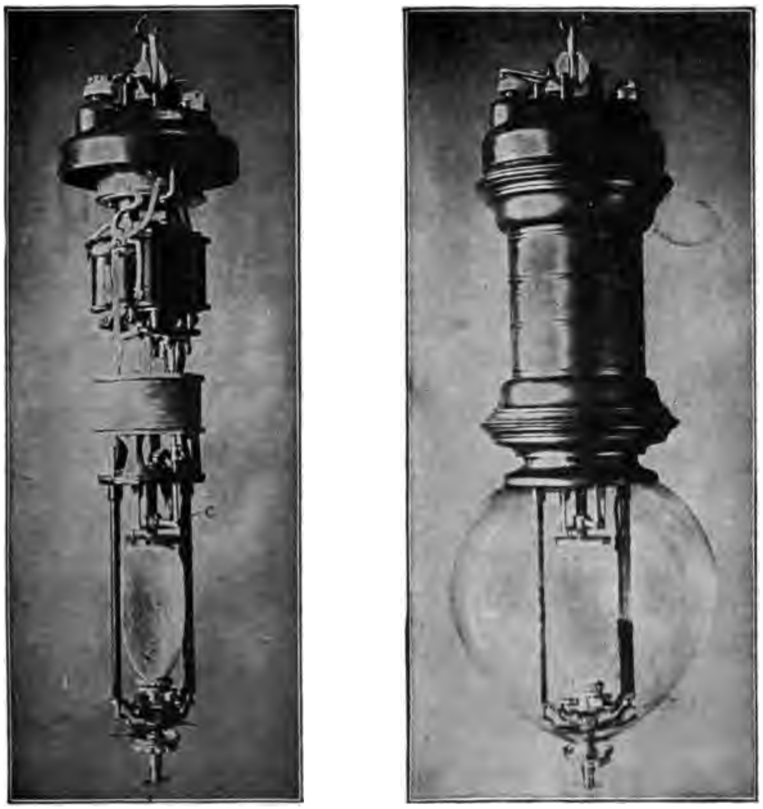


Fig. 30. Enclosed Arc Lamp Showing Carbon Feed Mechanism

Enclosed Type. Enclosed arcs for series systems are constructed much the same as the open lamp and are controlled by either shunt or differential mechanism. They require a voltage of from 68 to 75 at the arc and are usually constructed for from 5 to 6.8 amperes.

TABLE VII

Rating of Enclosed Arcs

D. C. Lamp	Current	Watts Consumed			Mean Intensity in H. U.			Mean Watts		
		In Lamp	In Arc	Mechanism	Spherical		Lower Hemi-spherical	Spherical H. U.		Lower Hemi-spherical
					Opal Outer	Clear Outer	Clear Outer	Opal Outer	Clear Outer	Clear Outer
						235	332		2.37	1.66
1	5.01	551	401	150	172	256*	362*	3.10	2.18*	1.52*
3	5.08	559	406	252	195	216	282	2.85	2.60	1.99
4	4.76	524	381	143	127	139	208	4.12	3.76	2.52
5	4.16†	458	333	125	154	174	221	2.96	2.63	2.07
7	4.76	524	381	143	203	333	317	2.63	2.20	1.65
9	4.84	532	387	145	182	226	281	2.83	2.38	1.89
10	4.99	549	399	150	202	242	309	2.74	2.24	1.77
12	4.87	536	390	146	178	195	230	3.05	2.66	2.33
Mean	4.9	529	384	144	176	207	272	3.03	2.60	1.98

A. C. Lamp	Current	In Lamp	Power Factor Lamp	In Arc	Power Factor Arc	Mechanism						
101	6.40	448	.63	340	.82	108	127	141	206	3.52	3.17	2.17
								203	236		2.26	1.94
102	6.79	459	.61	375	.73	84	146	176†	226†	3.31	2.60†	1.72†
103	5.89	424	.65	344	.75	80	116	130	147	3.66	3.15	2.88
105	6.20	414	.61	382	.80	32	128	187	219	3.24	2.20	1.89
								153	169		2.56	2.23
106	6.12	378	.56	298	.70	80	132	182†	284	2.82	2.19†	1.48†
108	6.48	457	.64	383	.80	74.5	133	175	211	3.20	2.61	2.16
110	6.18	339	.49	276	.72	63	140*	126	143	2.41*	2.68	2.37
Mean	6.29	417	.60	342	.76	74.5	130	159	190	3.31	2.66	2.23

*Condition of no outer globe. †Condition with shade on lamp. H. U. Hefner Units.

They also require a constant-current generator or a rectifier outfit, if used on alternating-current circuits. Table VII gives some data as to the rating of enclosed arcs on constant-potential circuits.

Constant-Potential Type. Constant-potential arcs must have some resistance connected in series with them to keep the voltage at the arc at its proper value. This resistance is made adjustable so that the lamps may be used on any circuit. Its location is clearly shown in Fig. 30, one coil being located above, the other below the operating solenoids.

Alternating-Current Arcs. These do not differ greatly in construction from the direct-current arcs. When iron or other metal parts are used in the controlling mechanism, they must be laminated, or so constructed as to keep down induced or eddy currents which might be set up in them. For this reason the metal spools, on which the solenoids are wound, are slotted at some point to prevent them from forming a closed secondary to the primary formed by the solenoid winding. On constant-potential circuits a reactive coil is used in place of a part of the resistance for cutting down the voltage at the arc.

Interchangeable Arcs. There are in the market interchangeable arcs which may be readily adjusted so as to operate on either direct or alternating current and on voltages from 110 to 220. Two lamps may be run in series on 220-volt circuits.

The distribution of light and the resulting illumination for the different lamps just considered will be taken up later. Aside from the distribution and quality of light, enclosed arcs have the advantage that the carbons are not consumed as rapidly as in the open lamp because the oxygen is soon exhausted from the inner globe and the combustion of the carbon is greatly decreased. They will burn from 80 to 100 hours without retrimming. The type of lamp most commonly employed requires 6.6 amperes for its operation.

FLAMING AND LUMINOUS ARC TYPES

Many thousands of enclosed carbon arc lamps, of both the direct-current and the alternating-current types are in use, and these lamps will be used to a considerable extent for some time to come; but other types of arc lamps, showing much higher efficiencies and having other very desirable characteristics, are now available and are replacing the carbon lamps in many instances. The high candle-power, high efficiency tungsten lamps are also used to replace carbon arcs in many instances.

Flaming Arc. In the carbon arc, the arc proper gives out but a small percentage of the total amount of light emitted. In order to obtain a light in which more of the source of luminosity is in the arc itself, experiments have been made with the use of electrodes impregnated with certain salts, as well as with electrodes of a material different from carbon. The result of these experiments has been to place upon the market the flaming arc lamps and the luminous arc lamps—lamps of high candle-power and good efficiency, and giving various colors of light. These lamps may be put in two classes: One class uses carbon electrodes, these electrodes being either impregnated with certain salts which add luminosity to the arc, or else they are fitted with cores which contain the required material; the other class covers lamps which do not employ carbon, the most notable example being the magnetite arc which uses a copper segment as one electrode and a magnetite stick as the other electrode.

Bremer Type. The Bremer flaming arc lamp was introduced commercially in 1899 and, since some of its principles are incorporated in many of the lamps on the market today, it will be briefly described here. The diagram shown in Fig. 31 illustrates the main features of this lamp. The electrodes are mounted at an angle and an electromagnet is placed above the arc for the purpose of keeping it from creeping up and injuring the economizer and also for the purpose of spreading the arc out and increasing its surface. The vapor from the arc is condensed on the economizer and this coating acts as a reflector, throwing the light downward. The economizer serves to limit the air supplied to the arc and thus increases the life of the electrodes. The inclined position of the carbons was suggested by the fact that in the impregnated carbons a slag was formed which gave trouble when the electrodes were mounted in the usual manner. By using the electrodes in this position there is little if any obstruction to the light which passes directly downward from the arc.

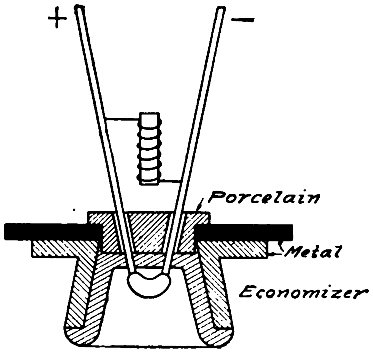


Fig. 31. Diagram of Bremer Flaming Arc

Bremer's original electrodes contained compounds of calcium, strontium, magnesium, etc., as well as boracic acid. Electrodes as employed in the various lamps today differ greatly in their make-up. Some use impregnated carbons; others use carbons with a core containing the flaming materials; and metallic wires are added in some cases. The life of electrodes for flaming lamps depends upon their length and upon the type of lamp. The maximum life of the treated carbons is in the neighborhood of 100 hours.

Color of Arc. The color of the light from the flaming arc is yellow when calcium salts are used as the main impregnating compound and many of the lamps installed use electrodes giving a yellow light. By employing more strontium, a red or pink light is produced; while if a white light is wanted, barium salts are used. Calcium gives the most efficient service and strontium comes between this and barium. The distribution curves in Fig. 32 illustrate the relative economies of the different materials. Modern electrodes contain not more than 15 per cent of added material proportioned so as to give the color required for different effects.

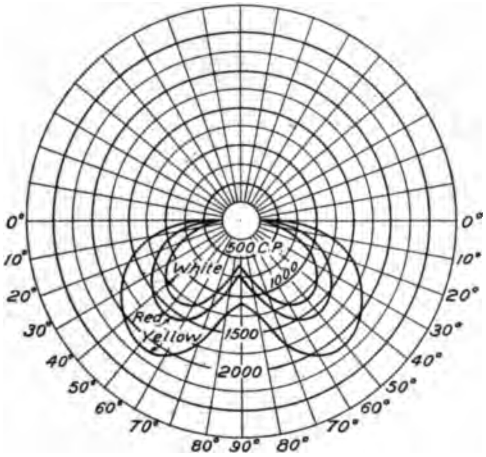


Fig. 32. Distribution Curves of a Flaming Arc

Characteristics and Advantages. The flaming arc lamp in some form is now manufactured by several firms. The modern lamp is known as the long-burning flame-carbon arc lamp. It possesses the following general characteristics: high efficiency, economical maintenance, steady burning, good light distribution, good color of light, comparatively low intrinsic brilliancy. In its most satisfactory form it is a lamp of comparatively high candle-power. Carbons for these lamps are from five-eighths inch to seven-eighths inch in diameter and the material for producing the flame is mixed with the carbon in the formation of the rods rather than introduced in the form of a core. The nature of the material used for impregnating the carbon determines the color given by the arc, as already explained.

TABLE VIII

Data for the Flaming Arc Lamps Compared in Fig. 35

	A. C. Series Lamp	D. C. Multiple Lamp
Terminal Volts	52	115
Terminal Watts	425	747.5
Arc Volts	46	70
Arc Watts	395	455
Amperes	10	6.5
Efficiency	93%	61
Power Factor	81.6%	......
Mean Hemispherical C. P.	1000	820
Mean Spherical C. P.	655	500
Mean H. S. C. P. per Watt	2.35	1.09
Mean Spherical C. P. per Watt	1.54	.67

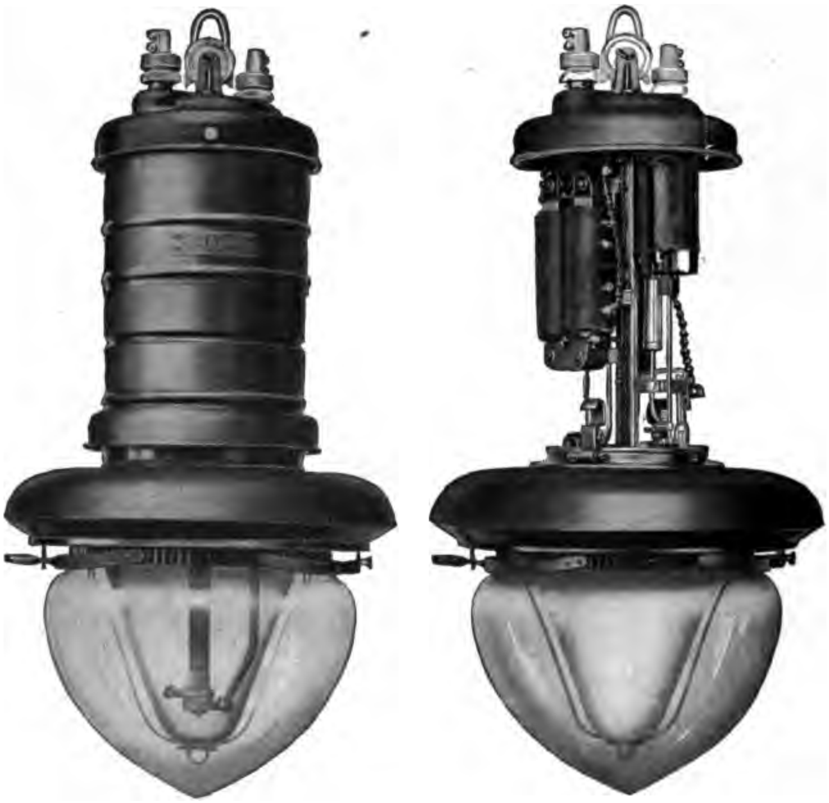


Fig. 33. Enclosed A. C. Series Flaming Arc Lamp with and without Hood
Courtesy of General Electric Company

The lamps are made for both direct-current and alternating-current operation. The best results are obtained with lamps requiring about 10 amperes for their operation and in these lamps the consumption of the carbons is at the approximate rate of one inch in 15 to 20 hours of burning. Lamps must be trimmed about every 100 hours.

Special care is necessary in the design of flaming-carbon arc lamps to see that the "soot", or condensation of the arc fumes, is not deposited where it will interfere with the light given by the lamp, or with the operating mechanism.

Fig. 33 illustrates the flaming arc lamp, this particular figure showing types manufactured by the General Electric Company. Fig. 34 is a diagram of a "sneak-feed" mechanism used in one make of flaming arc lamp. Fig. 35 gives a comparison between a 6.5-ampere direct-current multiple lamp and a 10-ampere alternating-current series unit. Table VIII gives data relative to the two lamps compared

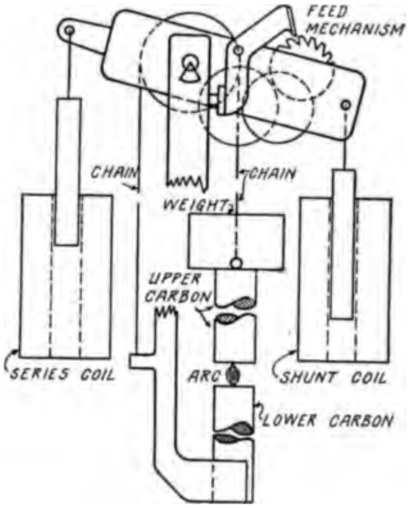


Fig. 34. Diagram Showing Principle of Sneak-Feed Mechanism for Flaming Carbon Arc Lamp

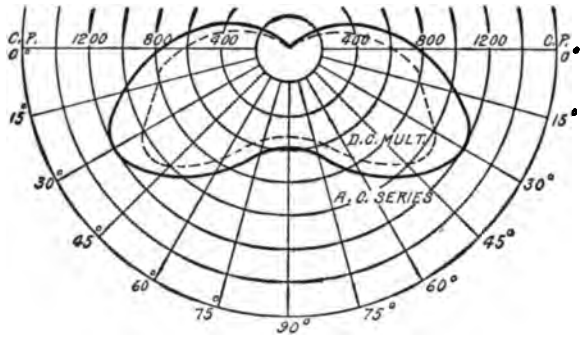


Fig. 35. Distribution Curves for Flaming Arc Lamps; D. C. Multiple Lamp for 6.5 Amperes; A. C. Series Lamp for 10 Amperes

in Fig. 35, and is illustrative of the performance of the modern unit. In general the modern type of lamp gives about 2.5 mean hemispherical candle-power per watt with "white" carbons and "Alba" glassware. With clear glassware the candle-power will run upwards of 5 mean hemispherical candle-power per watt consumption. "Yellow" carbons give from 30 to 50 per cent more light for the same energy consumption.

Luminous Arc. *Nature of Magnetite Electrodes.* The term luminous arc lamp is now reserved for the type of lamp at one time known as the "magnetite" or metallic arc lamp. Such lamps were introduced as early as 1903. The type most commonly employed uses a copper disc as one electrode and a magnetite stick—formed by forcing magnetite, to which titanium salts are usually added, into a thin sheet-steel tube—as the other electrode. This lamp gives a luminous arc of high efficiency and as the magnetite electrode is not consumed rapidly, magnetite lamps do not require frequent trimming. The life of the magnetite electrode, as at present manufactured, is

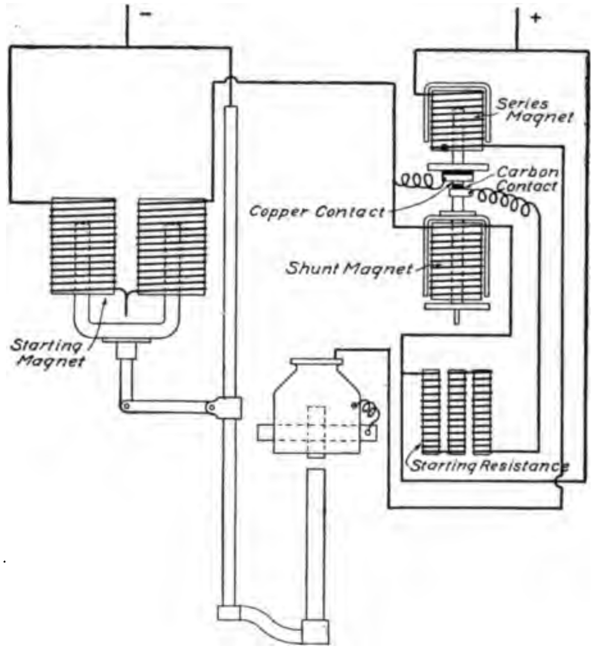


Fig. 36. Diagram of Connections for Luminous Arc Lamp

from 170 to 200 hours. A diagram of the connections of this lamp, as manufactured by the General Electric Company, is shown in Fig. 36. The magnetite electrode is placed below. The copper electrode has just the proper dimensions to prevent its being destroyed by the arc and yet it is not large enough to cause undue condensation of the arc vapor. Direct current must be used with this lamp, the current passing from the copper to the magnetite, and the light given by the lamp is white in color.

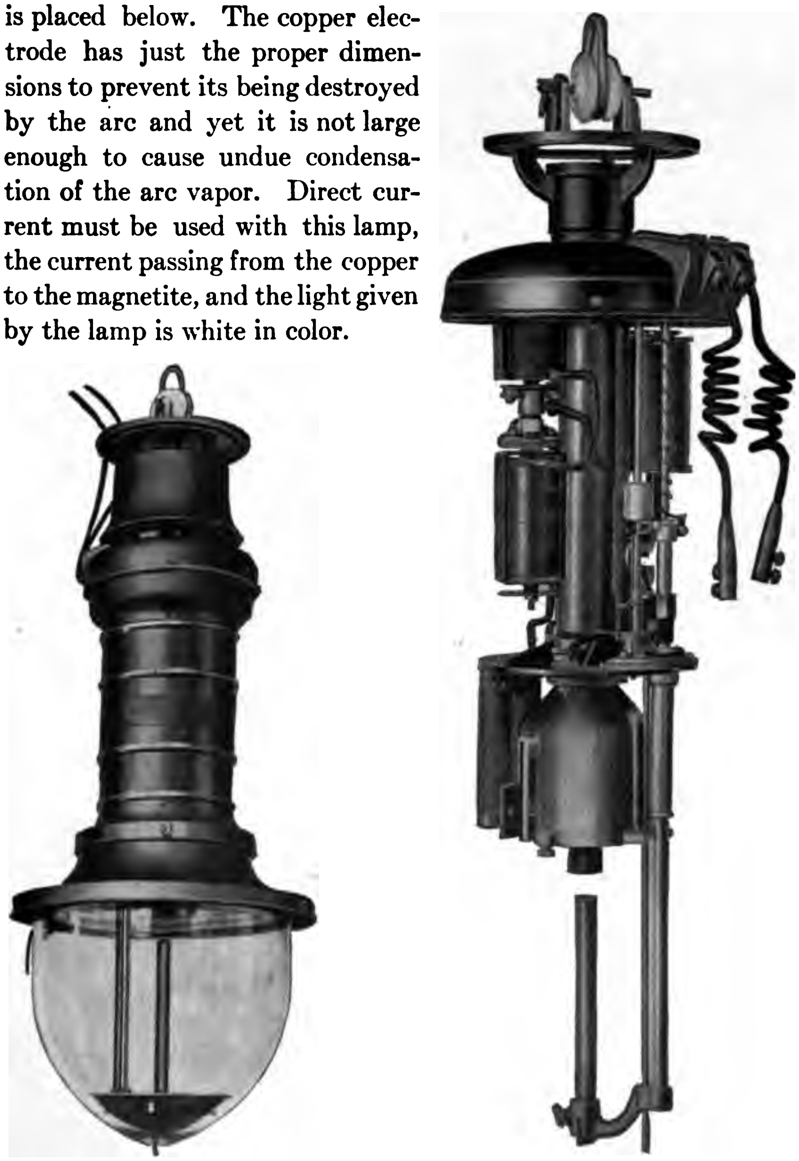


Fig. 37. Form 6 Series-Type 6.6-Ampere Luminous Arc Lamp
Courtesy General Electric Company

Specifications. The majority of the luminous arc lamps now in use (some 200,000) operate at about 75 volts at the arc and take 4 amperes, requiring 310 watts per unit. A 510-watt 6.6-ampere lamp is also standard. Fig. 37 illustrates the series luminous arc lamp as manufactured by the General Electric Company; and Fig. 38 shows the distribution curves for the 4-ampere and the 6.6-ampere units. The 4-ampere lamp gives a mean hemispherical candle-power of 545 while the 6.6-ampere unit gives a mean hemispherical candle-power of 1340. Metallic flame arc lamps are also made with a second metallic electrode used in place of the copper segment.

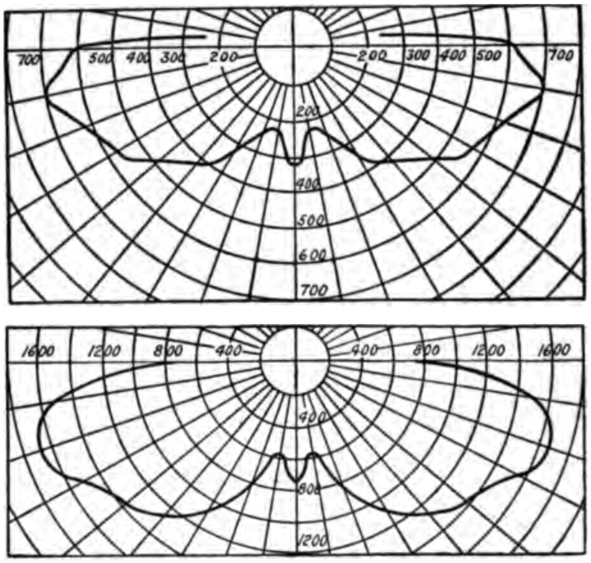


Fig. 38. Illumination Curves of 4-Ampere and 6.6-Ampere Luminous Arc Lamps

A very popular form of luminous arc lamp for ornamental street lighting is constructed with the controlling mechanism mounted below the arc proper and the lamp is enclosed in an ornamental globe and placed at the top of an ornamental standard.

Comparison of Arc Lamps. For the purpose of comparing the various types of arc lamps available, Table IX, prepared by Mr. S. W. Ash and published in the June, 1911, *Transactions of the Illuminating Engineering Society*, is given.

TABLE IX

Data on Arc Lamps

	Miniature Carbon 110 Volts 4 Amp. D. C.	Standard Multiple Carbon 110 Volts 5 Amp. D. C.	Standard Multiple Carbon 110 Volts 6½ Amp. D. C.	Intensified Arc 110 Volts 5 Amp. D. C.	Standard Multiple Carbon 110 Volts 6 Amp. 60 Cycle A. C.	Standard Multiple Carbon 110 Volts 7½ Amp. 60 Cycle A. C.	Twin Carbon multiple 220 volts 3½ Amp. D. C.	Standard Carbon 220 Volts 3¼ Amp. D. C.
Type of lamp	Miniature carbon	Standard multiple carbon	Standard multiple carbon	Intensified arc	Standard multiple carbon	Standard multiple carbon	Twin carbon multiple	Standard carbon
Volts at terminal	110 volts	110 volts	110 volts	110 volts	110 volts	110 volts	220 volts	220 volts
Volts at arc	83 volts	80 volts	80 volts	80 volts	72 volts	72 volts	2 arcs each 80 volts	150 volts
Current	4.1 amp. D. C.	5 amp. D. C.	6½ amp. D. C.	5 amp. D. C.	6 amp. 60 cycle A. C.	7½ amp. 60 cycle A. C.	3¼ amp. D. C.	3¼ amp. D. C.
Watts	451	550	715	550	430	540	715	715
Power factor					65%	65%		
Reflectors and glassware	White porcelain reflector, opal inner, no outer globe	Porcelain reflectors, light opal inner, no outer globe	Porcelain reflectors, light opal inner, no outer globe	Porcelain reflector, opal inner, no outer globe	Porcelain reflector, opal inner, no outer globe	Porcelain reflector, light opal inner, no outer globe	Porcelain reflectors, light opal inner, no outer globe	Porcelain reflectors, light opal inner, no outer globe
Electrodes	¼" carbon	½" carbon	½" carbon	Two ¼" upper ⅜" lower carbons	½" carbon	½" carbon	(2 pair) ½" carbon	½" carbon
Life of electrodes	50 hours	150 hours	100 hours	75 hours	125 hours	100 hours	150 hours	150 hours
Maximum, C. P.	440 at 60 degrees below horizontal	400 at 30 degrees below horizontal	580 at 30 degrees below horizontal	600 at 55 degrees below horizontal	230 at 30 degrees below horizontal	310 at 30 degrees below horizontal	280 at 30 degrees below horizontal	240 at 30 degrees below horizontal
Mean spherical, C. P.	218	215	318	225	160	215	195	160
Watts per M. S. C. P.	2.06	2.56	2.25	2.44	2.68	2.51	3.75	4.44
Mean hemispherical, C. P.	332	379	559	414	276	371	240	215
Watts per M. H. S. C. P.	1.36	1.45	1.28	1.33	1.56	1.45	3.05	3.43

TABLE IX—Continued

Data on Arc Lamps

	Series D. C. Open Carbon Arc 50 Volts 6.6 Amp.	Series D. C. Open Carbon Arc 50 Volts 9.6 Amp.	Series D. C. Enclosed Carbon Arc 75 Volts 6.6 Amp.	Series A. C. Enclosed Carbon 77 Volts 6.6 Amp.	Series A. C. Enclosed Carbon 77 Volts 7½ Amp. 60 Cycles	Flaming Arc 55 Volts 12 Amp. D. C.	Flaming Arc 55 Volts 12 Amp. A.C. 60 Cycles	Multiple Vertical Carbon Flame Arc 110 V. 6.5 Amp. D. C.
Type of lamp................	Series D. C. open carbon arc	Series D. C. open carbon arc	Series enclosed carbon arc	Series A. C. enclosed carbon	Series enclosed carbon	Flaming arc	Flaming arc	Multiple vertical carbon flame
Volts at terminal.............	50 volts	50 volts	75 volts	77 volts	77 volts	55 volts	55 volts	110 volts
Volts at arc....	48 volts	48 volts	73 volts	72 volts	72 volts	45 volts	45 volts	75 volts
Current......................	6.6 amp.	9.6 amp.	6.6 amp.	6.6 amp.	7½ amp. A. C. 60 cycles	12 amp.	12 amp.	6.5 amp.
Watts....	330	480	495	425	480	660	500	715
Power factor................				(Lamps only) 84%	(Lamps only) 84%		75%	
Reflectors and glassware........	Clear outer	Clear outer	Porcelain enameled iron reflectors, clear inner and outer globes	Porcelain enameled iron reflectors, clear inner and outer globes	Porcelain enameled iron reflector, clear inner and outer globes	Light opal globe	Light opal globe	40″ inverted diffuser alba globe
Electrodes	½″ carbon (2 pair)	⅝″ carbons (2 pair)	½″ carbon	½″ carbon	½″ carbon	Yellow ¼″	Yellow ¼″	Upper ½″ carbon lower only mineralized
Life of electrodes.............	18 hours	18 hours	125 hours	125 hours	100 hours	17 hours	17 hours	20 hours
Maximum, C. P................	720 at 45 degrees below horizontal	1250 at 45 degrees below horizontal	530 at 30 degrees below horizontal	250 at 20 degrees below horizontal	305 at 20 degrees below horizontal	2150 at 90 degrees below horizontal	1350 at 90 degrees below horizontal	2425 at 30 degrees below horizontal
Mean spherical, C. P...........	265	460	290	144	173	1460	875	1129
Watts per M. S. C. P...........	1.25	1.02	1.71	2.95	2.77	0.45	0.52	0.63
Mean hemispherical, C. P.......	395	690	479	232	291	1890	1170	2058
Watts per M. H. S. C. P........	.82	0.71	1.03	1.83	1.65	0.32	0.39	0.35

TABLE IX—Continued

Data on Arc Lamps

	Multiple Flame 110 Volts 5.5 Amp. D. C.	Multiple Flame 110 Volts 7 Amp A. C. 60 Cycles	Series Vertical Carbon Flame Arc 78 Volts 6.6 Amp. D. C.	Series Flaming Arc 50 Volts 12 Amp. A. C. 60 Cycles	Series Luminous Arc 78 Volts 4 Amp. D. C.	Series Luminous Arc 78 Volts 6.6 Amp. D. C.	Multiple Luminous Arc, 110 Volts 6.5 Amp. D. C.
Type of lamp....................	Multiple flame	Multiple flame	Series vertical flame arc	Series flaming arc	Series luminous arc	Series luminous arc	Multiple luminous arc
Volts at terminal................	110 volts	110 volts	78 volts	50 volts	78 volts	78 volts	110 volts
Volts at arc......................	70 volts	70 volts	75 volts	45 volts	75 volts	75 volts	75 volts
Current..........................	5.5 amp. D. C.	7 amp. A. C. 60 cycles	6.5 amp. D. C.	12 amp.	4 amp. D. C.	6.6 amp. D. C.	6.5 amp. D. C.
Watts............................	605	525	510	440	310	510	715
Power factor.....................		68%		75%			
Reflectors and glassware..........	Clear inner, opal outer porcelain enameled reflector	Porcelain enameled reflector, clear inner, opal outer globe	26" inverted diffuser alba globe	Opal outer	Clear outer	Clear outer	Clear globe
Electrodes	5/8" upper carbon 7/8" miner. lower	5/8" upper carbon 7/8" miner. lower	Upper 1/2" carbon lower only min.	Yellow	Upper copper slag, lower 1/2" magnetite	Upper copper slab, lower 11/16" magnetite	Upper copper slab, lower 1/2" magnetite
Life of electrodes................	60 hours	50 hours	20 hours	12 hours	175 hours	125 hours	80 hours
Maximum, C. P....................	1500 at 30 degrees below horizontal	1250 at 30 degrees below horizontal	2350 at 30 degrees below horizontal	1350 at 90 degrees below horizontal	700 at 10 degrees below horizontal	1650 at 10 degrees below horizontal	1650 at 10 degrees below horizontal
Mean spherical, C. P.............	706	583	1223	875	285	720	720
Watts per M. S. C. P.............	0.80	0.90	0.42	0.50	112	0.71	0.99
Mean hemispherical, C. P.........	1210	875	2051	1170	545	1340	1340
Watts per M. H. S. C. P..........	0.50	0.60	0.25	0.37	0.59	0.38	0.53

POWER DISTRIBUTION

The question of power distribution for electric lamps and other appliances is taken up fully in the section on that subject; therefore, it will be treated very briefly here. The systems may be divided into:

(1) Series distribution systems.
(2) Multiple-series or series-multiple systems.
(3) Multiple or parallel systems.
They apply to both alternating and direct current.

Series System. The series distribution system is the simplest of the three; the lamps, as the name indicates, are connected in series as shown in Fig. 39. A constant load is necessary if a constant potential is to be used. If the load is variable, a constant-current generator or a special regulating device is necessary. Such devices are constant-current transformers and constant-current regulators as applied to alternating-current circuits.

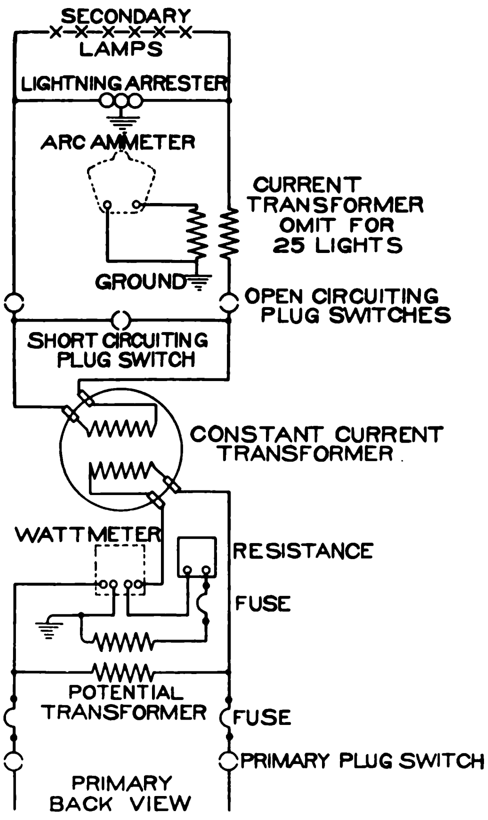
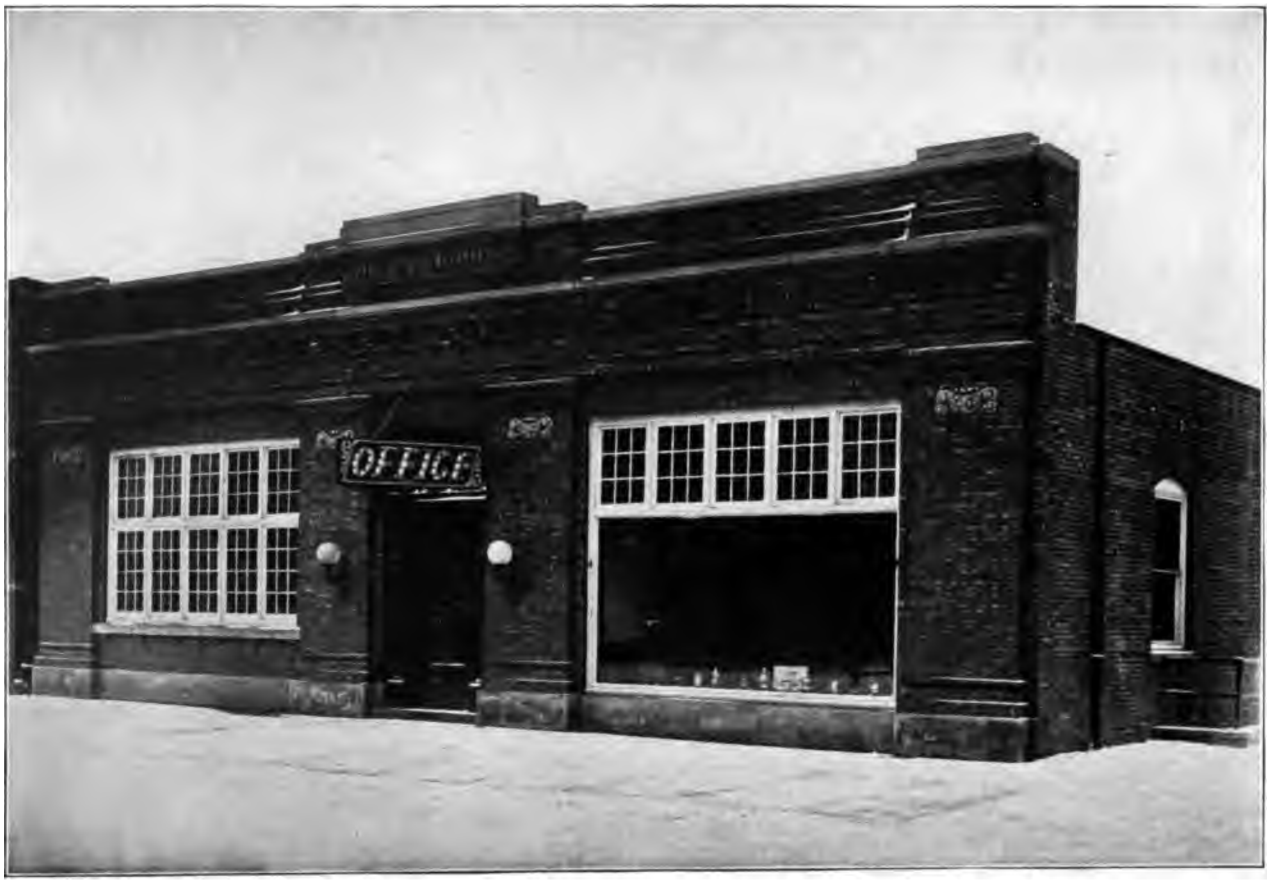


Fig. 39. Wiring Diagram for Single-Coil Transformer

Most Used for Street Illumination. The series system is used mostly for arc and incandescent lamps when applied to street illumination. Its advantages are simplicity and the saving of copper. The disadvantages are high voltage, as fixed by the number of lamps in series, the limitation of the size of the machines, since they cannot be insulated for voltage above about 6000; and the fact that a single open circuit shuts down the whole system.



WEST SIDE BUILDING FOR THE CLEVELAND ELECTRIC ILLUMINATING COMPANY, CLEVELAND, OHIO
Watterson and Schneider, Architects, Cleveland, Ohio
For details see pages 251 and 266

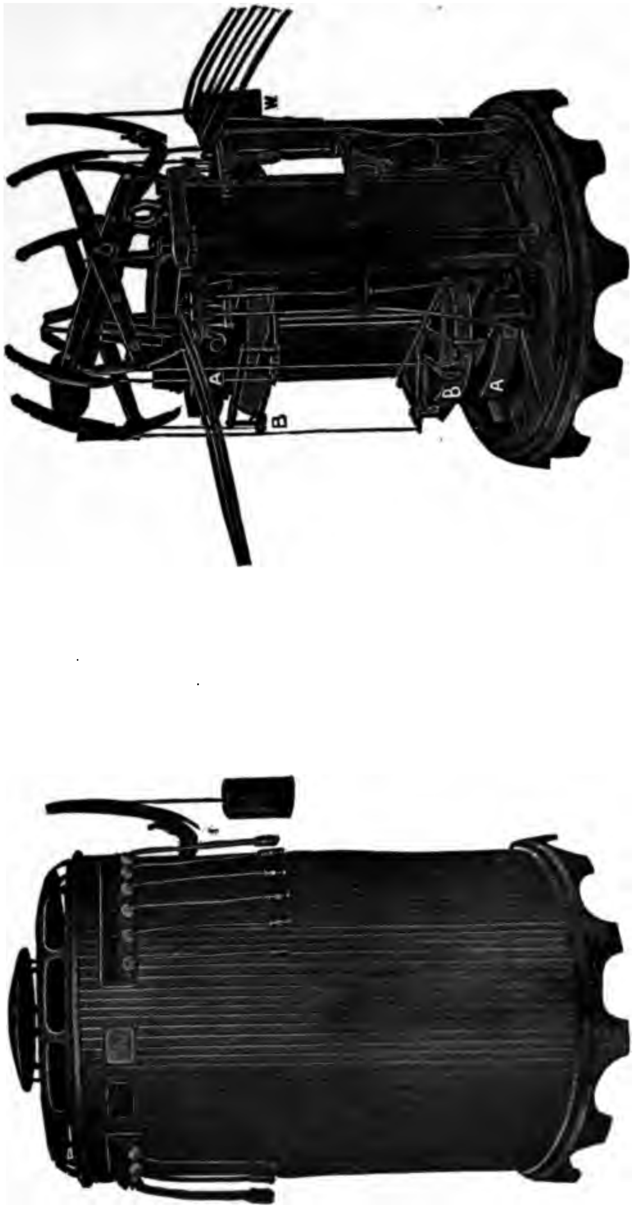


Fig. 40. Double-Coil Transformer (second view with case removed)

Alternating-current series distribution systems are being used to a very large extent. By the aid of special transformers, or regulators, any number of circuits can be run from one machine or set of busbars, and apparatus can be built for any voltage and of any size. It is not customary, however, to build transformers of this type having a capacity greater than one hundred 6.6-ampere lamps because of the high voltage which would have to be induced in the secondary for a larger number of lamps.

Description of Single-Coil Transformer for A. C. Series Circuits. Fig. 39 gives a diagram of the connection of a single-coil transformer in service. The constant-current transformer most in use for lighting purposes is the one manufactured by the General Electric Company and commonly known as a "tub transformer". Fig. 40 shows such a transformer (double-coil type) when removed from the case.

Referring to Fig. 40, the fixed coils A form the primaries which are connected across the line; the movable coils B are the secondaries connected to the lamps. There is a repulsion of the coils B by the coils A when the current flows in both circuits and this force is balanced by means of the weights at W, so that the coils B take a position such that the normal current will flow in the secondary. On light loads, a low voltage is sufficient; hence the secondary coils are close together near the middle of the machine and there is a heavy magnetic leakage. When all of the lamps are on, the coils take the position shown when the leakage is a minimum and the voltage a maximum. When first starting up, the transformer is short-circuited and the secondary coils are brought close together. The short circuit is then removed and the coils take a position corresponding to the load on the line.

These transformers regulate from full load to one-third rated load within one-tenth ampere of normal current, and can be run on short circuit for several hours without overheating. The efficiency is given as 96 per cent for 100-light transformers and 94.6 per cent for 50-light transformers at full load. The power factor of the system is from 76 to 78 per cent on full load and, owing to the great amount of magnetic leakage at less than full load—the effect of leakage being the same as the effect of an inductance in the primary —the power factor is greatly reduced, falling to 62 per cent at three-fourths load, 44 per cent at one-half load, and 24 per cent at one-fourth load.

Standard sizes are for capacities of 25, 35, 50, 75, and 100 enclosed arcs of the 6.6 ampere size and they are also made for lower currents in the neighborhood of 3.3 amperes for incandescent lamps. The low power factor of such a system on light loads shows that a transformer should be selected of such a capacity that it will be fully or nearly fully loaded at all times. The primary winding can be constructed for any voltage and the open-circuit voltages of the secondaries are as follows:

25-light transformer, 2300 volts	75-light transformer, 6900 volts
35- " " 3200 "	100- " " 9200 "
50- " " 4600 "	

The 50,- 75-, and 100-light transformers are arranged for multiple-circuit operation—two circuits used in series—and the voltages at full load reach 4100 for each circuit on the 100-light machine.

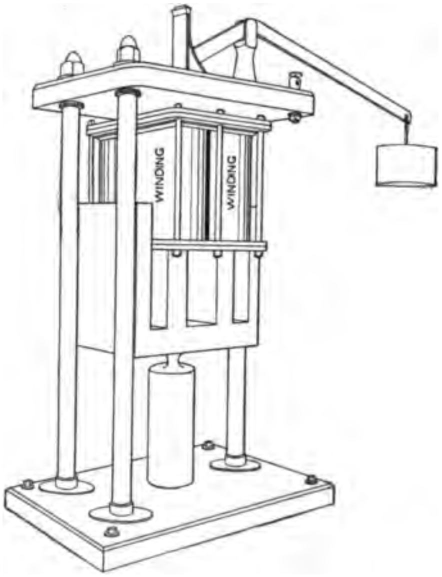


Fig. 41. Current Regulator for A. C. Series Distribution Systems

Constant Potential Transformer and Regulator for A. C. Series Circuits. The second system, used for series distribution on alternating-current circuits, consists of a constant-potential transformer, stepping down the line voltage to that required for the total number of lamps on the system and allowing 83 volts for each lamp. In series with the lamps is a reactive coil, the reactance of which is automatically regulated, as the load is increased or decreased, in order to keep the current in the line constant. Fig. 41 shows such a regulator and Fig. 42 shows this regulator connected in circuit. The inductance is varied by the movement of the coil so as to include more or less iron in the magnetic circuit. Since the inductance in series with the lamps is high on light loads, the power factor is greatly reduced as in the constant-current transformer; and the circuits should, preferably, be run fully loaded; 60 to 65 lamps on a circuit is the usual maximum limit.

While used primarily for arc-light circuits, the same systems, designed for lower currents, are very readily applied to series incandescent systems.

Use of Mercury Arc Rectifier with Flaming or Luminous Arcs. The introduction of certain flaming or luminous arcs requiring direct current for their operation has led to the use of the mercury arc rectifier in connection with series circuits on alternating-current systems. A constant-current transformer is used to regulate for the proper constant current in its secondary winding and this secondary current is rectified by means of the mercury arc rectifier for the lamp circuit. In the recent outfits the rectifier tubes are immersed in oil for cooling. While this rectifier was first introduced for the operation of luminous arc lamps, there is no reason why it should not be used with any series lamp requiring direct current, provided the system is designed for the current taken by such lamps. With this system any commercial frequency may be used. Sets are constructed for 25-, 50-, and 75-light circuits. They have a combined efficiency-transformer and rectifier-tube, of 85 to 90 per cent, and operate at a power factor of from 65 to 70 per cent. Fig. 43 gives a diagram of the circuit and rectifier connections used with a single-tube outfit.

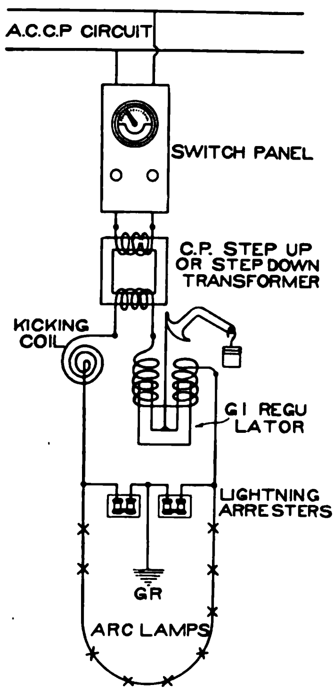


Fig. 42. Wiring Diagram Showing Introduction of the Current Regulator

Multiple-Series or Series-Multiple Systems. Multiple-series or series-multiple systems combine several lamps in series and these series groups in multiple, or several lamps in multiple and these multiple groups in series, respectively. They have but a limited application.

Multiple, or Parallel, Systems. *Characteristics of System.* By far the largest number of lamps in service are connected to parallel systems of distribution. In this system, the units are connected across the lines leading to the busbars at the station, or to the secondaries of constant-potential transformers. Fig. 44 shows a diagram of ten lamps connected in parallel. The current delivered by the machine depends directly on the number of lamps connected in service, the voltage of the system being kept constant.

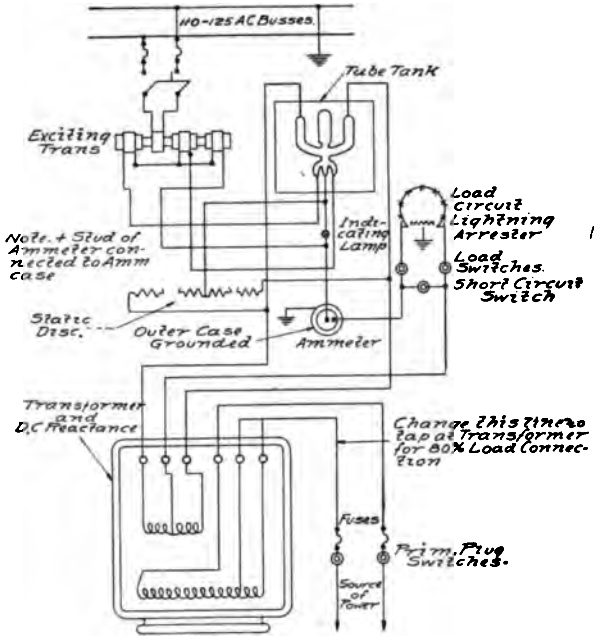


Fig. 43. Wiring Diagram for A. C. System Showing Mercury Arc Rectifier

Inasmuch as the flow of current in a conductor is always accompanied by a fall of potential equal to the product of the current flowing into the resistance of the conductor, the lamps at the end of the system shown will not have as high a voltage impressed upon them as those nearer the machine. To overcome this serious obstacle in multiple systems, various regulation schemes have been adopted.

Methods of Regulation. The regulating systems are as follows:

(1) Cylindrical conductors, parallel feeding.
(2) Conical conductors, parallel feeding.
(3) Cylindrical conductors, antiparallel feeding.
(4) Conical conductors, antiparallel feeding.

In the cylindrical-conductor parallel-feeding system, the conductors *AB* and *CD*, Fig. 44, are of the same size throughout and are fed at the same end by the generator. The voltage is a minimum at the lamps *E* and a maximum at the lamps *F*, the value of the voltage at any lamp being readily calculated.

By a conical or tapering conductor is meant a conductor whose diameter is so proportioned throughout its length that the current, divided by the cross section, or the current density, is a constant quantity. Such a conductor is approximated in practice by using smaller sizes of wire as the current in the lines becomes less.

In an antiparallel system, the current is fed to the lamps from opposite ends of the system, as shown in Fig. 45.

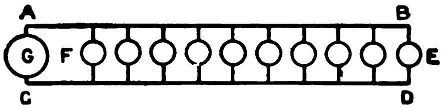


Fig. 44. Parallel Feeding System

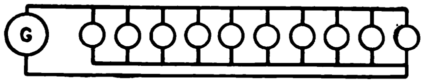


Fig. 45. Antiparallel Feeding System

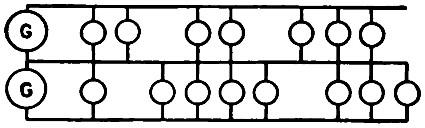


Fig. 46. Three-Wire System

Multiple-Wire Systems. In order to take advantage of a higher voltage for distribution of power to the lighting circuits, 3- and 5-wire systems have been introduced, the 3-wire system being used to a very large extent. In this system, three conductors are used, the voltage from each outside conductor to the middle neutral conductor being the same as for a simple parallel system. Fig. 46 gives a diagram of this. By this system the amount of copper required for a given number of lamps is from five-sixteenths to three-eighths of the amount required for a 2-wire distribution, depending on the size of the neutral conductor. The saving of copper together with the disadvantages of the system is more fully treated in the paper on "Power Transmission".

ILLUMINATION

Illumination may be defined as the quality and quantity of light which aids in the discrimination of outline and the perception of color. Not only the quantity, but the quality of the light, as well as the arrangement of the units, must be considered in a complete study of the subject of illumination.

Unit of Illumination. The unit of illumination is the *foot candle* and its value is the amount of light falling on a surface at a distance of one foot from a source of light one candle-power in value. The law of inverse squares—namely, that the illumination from a given source varies inversely as the square of the distance from the source—shows that the illumination at a distance of 2 feet from a single candle-power unit is .25 foot candle. For further consideration of the law of inverse squares, see "Photometry", p. 111.

Illumination may be classified as useful—when used for the ordinary purposes of furnishing light for carrying on work, taking the place of daylight; and scenic—when used for decorative lighting, such as stage lighting, etc. The two divisions are not, as a rule, distinct, but the one is combined with the other.

Intrinsic Brightness. By intrinsic brightness is meant the amount of light emitted per unit surface of the light source. Table X gives the intrinsic brightness of several light sources.

Regular Reflection. Regular reflection is the term applied to reflection of light when the reflected rays are parallel. It is of such a nature that the image of the light source is seen in the reflection. The reflection from a plane mirror is an example of this. It is useful in lighting in that the direction of light may be changed without complicating calculations aside from deductions necessary to compensate for the small amount of light absorbed.

Irregular Reflection. Irregular reflection, or diffusion, consists of reflection in which the reflected rays of light are not parallel but take various directions, thus destroying the image of the light source. Rough unpolished surfaces give such reflection. Smooth unpolished surfaces generally give a combination of two kinds of reflection. Diffused reflection is very important in the study of illumination inasmuch as diffused light plays an important part in the lighting of

TABLE X

Intrinsic Brightness of Light Sources

	CANDLE-POWER PER SQ. IN.
Moore tube	0.3 — 1.75
Frosted incandescent	2 — 5
Candle	3 — 4
Gas flame	3 — 8
Oil lamp	3 — 8
Cooper-Hewitt lamp	17
Welsbach gas mantle	20 — 50
Acetylene	75 — 100
Enclosed A. C. arc	75 — 200
Enclosed D. C. arc	100 — 500
Incandescent lamps	
Carbon 3.5 watts per candle	375
Carbon 3.1 watts per candle	480
Metallized carbon 2.5 watts per candle	625
Tantalum 2.0 watts per candle	750
Tungsten 1.25 watts per candle	875
Tungsten 1.15 watts per candle	1000
Nernst 1.5 watts per candle	2200
Sun on horizon	2000
Flaming arc	5000
Open arc lamp	10,000–50,000
Open arc crater	200,000
Sun 30° above horizon	500,000
Sun at zenith	600,000

interiors. This form of reflection is seen in many photometer screens. Light is also diffused when passing through semitransparent shades or screens.

In considering reflected light, we find that, if the surface on which the light falls is colored, the reflected light may be changed in its nature by the absorption of some of the colors. Since, as has been said, the reflected light in interior lighting forms a large part of the source of illumination, this illumination will depend upon the nature and the color of the reflecting surfaces.

Whenever light is reflected from a surface, either by direct or diffused reflection, a certain amount of light is absorbed by the surface. Table XI gives the amount of white light reflected from different materials.

From this table it is seen that the light-colored papers reflect the light well but, of the darker colors, only yellow has a comparatively high coefficient of reflection. Black velvet has the lowest value but this only holds when the material is free from dust. Rooms with

TABLE XI

Relative Reflecting Power

MATERIAL	%
White blotting paper	82
White cartridge paper	80
Chrome yellow paper	62
Orange paper	50
Yellow wall paper	40
Light pink paper	36
Yellow cardboard	30
Light blue cardboard	25
Emerald green paper	18
Dark brown paper	13
Vermilion paper	12
Blue-green paper	12
Black paper	5
Black cloth	1.2
Black velvet	.4

dark walls require a greater amount of illuminating power, as will be seen later.

RESIDENCE LIGHTING

Types of Lamps. The lamps used for residence lighting are limited to the less powerful units—namely, carbon or tungsten lamps varying in candle-power from 8 to 40 per unit. These should always be shaded so as to keep the intrinsic brightness low. The intrinsic brilliancy should seldom exceed 2 to 3 candle-power per square inch and its reduction is usually accomplished by appropriate shading. Arc lights are so powerful as to be uneconomical for small rooms, while the color of the mercury-vapor light is an additional objection to its use.

Plan of Illumination. Lamps may be selected and so located as to give a brilliant and fairly uniform illumination in a room; but this is an uneconomical scheme and the one more commonly employed is to furnish a uniform, though comparatively weak, ground illumination and to reinforce this at points where it is necessary or desirable. The latter plan is satisfactory in almost all cases and the more economical of the two.

While the use of units of different power is to be recommended, where desirable, lights differing in color should not be used for lighting the same room. As an exaggerated case, the use of arc lamps with incandescent lamps might be mentioned, the arcs being so much whiter than the incandescent lamps that the latter appear distinctly yellow when the two are viewed at the same time.

Calculation of Illumination. *Point-by-Point Method.* In determining the value of illumination, not only the candle-power of the units but the amount of reflected light must be considered for the given location of the lamps. Following is a formula based on the coefficient of reflection of the walls of the room, which serves for preliminary calculations:

$$I = \frac{c.p. \dfrac{1}{1-k}}{d^2}$$

I is illumination in foot candles; $c.p.$ is candle-power of the unit; k is coefficient of reflection of the walls; d is distance from the unit in feet.

Where several equal units are used, this formula becomes

$$I = c.p.\left(\frac{1}{d^2} + \frac{1}{d_1^2} + \frac{1}{d_2^2} + \text{----------}\right)\frac{1}{1-k}$$

or

$$c.p. = \frac{I}{\left(\dfrac{1}{d^2} + \dfrac{1}{d_1^2} + \dfrac{1}{d_2^2} + \text{----------}\right)\dfrac{1}{1-k}}$$

where d, d_1, d_2, etc., equal the distances from the point considered to the various light sources. If the lamps are of different candle-power, the illumination may be determined by combining the illumination from each source as calculated separately. An example of calculation is given on page 64.

Correction for Angle of Lights with Plane of Illumination. The above method is not strictly accurate because it does not take account of the angle at which the light from each one of the sources strikes the assumed plane of illumination. If the ray of light is perpendicular to the plane, the formula $I = \frac{c.p.}{d^2}$ gives correct values. If a is the angle which the ray of light makes with a line drawn from the light source perpendicular to the assumed plane, then the formula becomes

$$I = \frac{c.p. \times \cos a}{d^2}$$

Therefore, by multiplying the candle-power value of each light source in the direction of the illuminated point by the cosine of each angle *a*, a more accurate result will be obtained.

It is readily seen that the effect of reflected light from the ceilings is of more importance than that from the floor of a room. The value of *k*, in the above formula, will vary from 60 per cent to 10 per cent, but for rooms with a fairly light finish 50 per cent may be taken as a good average value.

Amount of Light Necessary. The amount of illumination will depend on the use to be made of the room. One foot candle gives sufficient illumination for easy reading, when measured normal to the page, and probably an illumination of .5 foot candle on a plane 3 feet from the floor forms a sufficient ground illumination. The illumination from sunlight reflected from white clouds is from 20 foot candles up, while that due to moonlight is in the neighborhood of .03 foot candle. It is not possible to produce artificially a light equivalent to daylight on account of the great amount of energy that would be required and the difficulty of obtaining proper diffusion.

The method of calculating the illumination of a room that has just been described is known as the *point-by-point* method and it gives very accurate results, if account is taken of the angle at which the light from each source strikes the plane of illumination and if the light distribution curves of the units and the value of *k* have been carefully determined. Under these conditions, however, the calculations become extended and complicated, and methods only approximate, but simpler in their application, are being introduced. One method, which gives good results when applied to fairly large interiors, makes the flux of light from the light sources the basis of calculation of the average illumination.

Flux of Light Method. Flux of light is measured in lumens and a lumen is the amount of light which must fall on one square foot of surface in order to produce a uniform illumination of an intensity of one foot candle. A source of light giving one candle-power in every direction and placed at the center of a sphere of one foot radius would give an illumination of one foot candle at every point in the surface of the sphere and the total flux of light would be 4π, or 12.57 lumens, since the area of the sphere would be 4π, or 12.57 square feet. A lamp giving one mean spherical candle-power gives a flux of 12.57 lumens and the total flux of light from any source is obtained by multiplying its mean spherical candle-power by 12.57. In calculating illumination it is customary to determine the illumination on a plane about 30 inches from the floor for desk work, and about 42 inches from the floor for the display of goods on counters. If we determine the total number of lumens falling on this plane and divide this number by the area of the plane, we obtain the average illumination in foot candles. This of course tells us nothing about the maximum or minimum value of the illumination and such values must be obtained by other methods, if they are desired. Reflected light, other than that covered by the distribution curve of the light unit including its reflector, is usually neglected in this method of calculation.

We may assume that in large rooms the light coming from the lamp within an angle of 75 degrees from the vertical reaches the plane of illumination. In smaller rooms this angle should be reduced to about 60 degrees. In order to determine the flux of light within this angle a Rousseau diagram, which is described later, should be drawn. By means of this diagram the average candle-power of the light source within the angle assumed may be readily determined, and this mean value, multiplied by 12.57, will give the flux of light in lumens. This method of calculation, together with some guides for its rapid application, is described by Messrs. Cravath and Lansingh in *Transactions of the Illuminating Engineering Society:* 1908. The same authorities give the following useful data:

To determine the watts required per square foot of floor area, multiply the intensity of illumination desired by the constants given, as follows:

INTENSITY CONSTANTS FOR INCANDESCENT LAMPS

Tungsten lamps rated at 1.25 watts per horizontal candle-power; clear prismatic reflectors, either bowl or concentrating; large room; light ceiling; dark walls; lamps pendant; height from 8 to 15 feet	.25
Same with very light walls	.20
Tungsten lamps rated at 1.25 watts per horizontal candle-power; prismatic bowl reflectors enameled; large room; light ceiling; dark walls; lamps pendant, height from 8 to 15 feet	.29
Same with very light walls	.23
Gem lamps rated at 2.5 watts per horizontal candle-power; clear prismatic reflectors, either concentrating or bowl; large room; light ceiling; dark walls; lamps pendant; height from 8 to 15 feet	.55
Same with very light walls	.45

Carbon filament lamps rated at 3.1 watts per horizontal candle-power; clear prismatic reflectors, either bowl or concentrating; light ceiling; dark walls; large room; lamps pendant; height from 8 to 15 feet	**.65**
Same with very light walls	**.55**
Bare carbon filament lamps rated at 3.1 watts per horizontal candle-power; no reflectors; large room; very light ceiling and walls; height from 10 to 14 feet	**.75 to 1.5**
Same; small room; medium walls	**1.25 to 2.0**
Carbon filament lamps rated at 3.1 watts per horizontal candle-power; opal dome or opal cone reflectors; light ceiling; dark walls; large room; lamps pendant; height from 8 to 15 feet	**.70**
Same with light walls	**.60**

INTENSITY CONSTANTS FOR ARC LAMPS

5-ampere, enclosed direct-current arc on 110-volt circuit; clear inner, opal outer globe; no reflector; large room; light ceiling; medium walls; height from 9 to 14 feet	**.50**

Lighting Arrangement. An arrangement of lamps giving a uniform illumination cannot well be applied to residences on account of the number of units required and the inartistic effect. We are limited to chandeliers, side lights, or ceiling lights, in the majority of cases, with table or reading lamps for special illumination.

When ceiling lamps are used and the ceilings are high, some form of reflector or reflector lamp is recommended. In any case where the coefficient of reflection of the ceilings is less than 40 per cent, it is more economical to use reflectors. When lamps are mounted on chandeliers, the illumination is far from uniform, being a maximum in the neighborhood of the chandelier and a minimum at the corners of the room. By combining chandeliers with side lights it is generally possible to get a satisfactory arrangement of lighting for small or medium-sized rooms.

As a check on the candle-power in lamps required, we have the following:

Illumination of Room for Different Arrangements of Lamps. As an example of the calculation of the illumination of a room with different arrangements of the units of light, assume a room 16 feet square, 12 feet high, and with walls having a coefficient of reflection of 50 per cent. Consider first the illumination on a plane 3 feet above the floor when lighted by a single group of lights mounted at the center of the room 3 feet below the ceiling. If a minimum value of .5 foot candle is required at the corner of the room, we have the equation (point-by-point method)

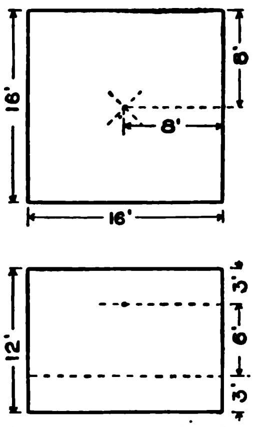


Fig. 47. Diagram Showing Method of Calculating Room Illumination

$$.5 = c.\,p.\frac{1}{12.8^2} \times \frac{1}{1-.5}$$

since $d = \sqrt{8^2+8^2+6^2} = 12.8$ (See Fig. 47). Solving for the value of *c. p.*, we have

$$c.\,p. = \frac{.5}{\frac{1}{164} \times \frac{1}{.5}} = .5 \times 82 = 41$$

Three 16-candle-power lamps would serve this purpose very well.

To determine the illumination directly under the lamp, we have

$$I = 48 \times \frac{1}{6^2} \times \frac{1}{1-.5} = \frac{48}{36} \times 2 = 2.7 \text{ ft.-candles.}$$

This value is five times the value of the illumination at the corners of the room.

Next consider four 8-candle-power lamps located on the side walls 8 feet above the floor, as shown in Fig. 48. Calculating the illumination at the center of the room on a plane 3 feet above the floor, we have

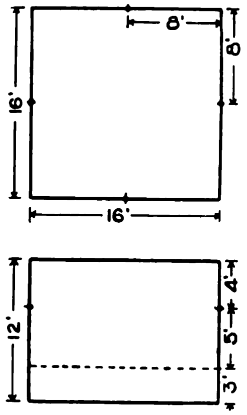


Fig. 48. Diagram for Four 8-C.P. Lamps on Side Wall

$$I = 8\left(\frac{1}{89} + \frac{1}{89} + \frac{1}{89} + \frac{1}{89}\right)\frac{1}{1-.5}$$

$$d^2 = 8^2 + 5^2 = 64 + 25 = 89$$

$$I = 8 \times \frac{4}{89} \times 2 = .72 \text{ foot candle}$$

The illumination at the corner of the room would be

$$I = 8\left(\frac{1}{89} + \frac{1}{89} + \frac{1}{345} + \frac{1}{345}\right)\frac{1}{1-.5}$$

$$= 8\left(\frac{2}{89} + \frac{2}{345}\right) \times 2 = .45 \text{ foot candle}$$

In a similar manner the illumination may be calculated for any point in the room or a series of points may be taken and curves

TABLE XII

A Typical Residence Installation

Room	No of Lights	Globe or Reflector	Remarks
Hall (front) 10′×4′ 6″	1 10-watt Mazda	Opalescent enclosing globe	Walls dark green, ceiling white Lamp 7′ above floor
Living room 13′×14′	1 60-watt Mazda 2 15-watt Mazda portable	Semi-indirect opalescent bowl	Walls dark green, ceiling white Lamp 7′-6″ above floor
Dining room	1 60-watt Mazda 3 15-watt Mazda	Dome with silk diffusing screen underneath Back of art-glass window	Lamp 4′-9″ from floor
Den 11′×10′	1 100-watt Mazda 1 25-watt desk lamp	Total indirect lighting fixture	Walls dark green, ceiling white Lamp 7′-3″ above floor
Pantry	1 15-watt Mazda	Semi-indirect, opalescent bowl	Walls buff, ceiling white
Hall (rear)	1 15-watt Mazda	Lamp frosted, opal shade	Lamp 7′-6″ above floor
Bathroom 9′×6′	1 25-watt Mazda 1 25-watt Mazda	Opalescent glass, bowl-shaped reflector Metal reflector	Bracket lamp 5′-6″ from floor Mounted at right of mirror
Bedroom 10′×14′	1 15-watt Mazda 1 40-watt Mazda	Cylindrical diffusing shade Deep bowl-shaped diffusing shade	Bracket lamp Ceiling lamp 7-′8″ above floor
Kitchen 9′×11′	1 40-watt Mazda	Extensive prismatic reflector	Lamp 7′-6″ from floor

plotted, showing the distribution of the light as well as the areas having the same illumination. Where refined calculations are desired, the correct distribution curve of the lamp must be made use of in order to determine the candle-power in different directions in the room.

Illumination Calculations After Lights Are Installed. By means of the Weber, or some other form of portable photometer, curves as plotted from calculations may be readily checked after the lamps are installed. When lamps are to be permanently located, the question of illumination becomes an important one and it may be desirable to determine, by calculation, the illumination curves for each room before installing the lamps. This applies to the lighting of large interiors more particularly than to residence lighting. The point-by-point method of calculation is used for very accurate work when the system of illumination admits of this method. Other methods are often simpler and sufficiently accurate for practical work.

Typical Arrangement for Small Residence. In house lighting the decorative element predominates, yet the illumination should be satisfactory and the system should be economical in its operation. As typical of a satisfactory and inexpensive lighting system in a small residence, Table XII, compiled for an article, by Mr. A. L. Powell, published in the *Transactions of the Illuminating Engineering Society*, is given.

Rules for Good Residence Illumination. Before passing on to the subject of the lighting of larger interiors it would be well to call attention to some of the salient points of good lighting as they are set forth in the little primer on illumination, "Light: Its Use and Misuse", published by the Illuminating Engineering Society, New York City, as these principles apply very directly to the plans for residence lighting systems:

Illumination cannot be judged by the brightness of lamps.

Flickering sources of light are to be avoided.

The eyes should not be subjected to an unshaded lamp.

Light should come from above the eyes, not from below or on a level with the eyes.

Place lamps so that one does not have to face them when reading.

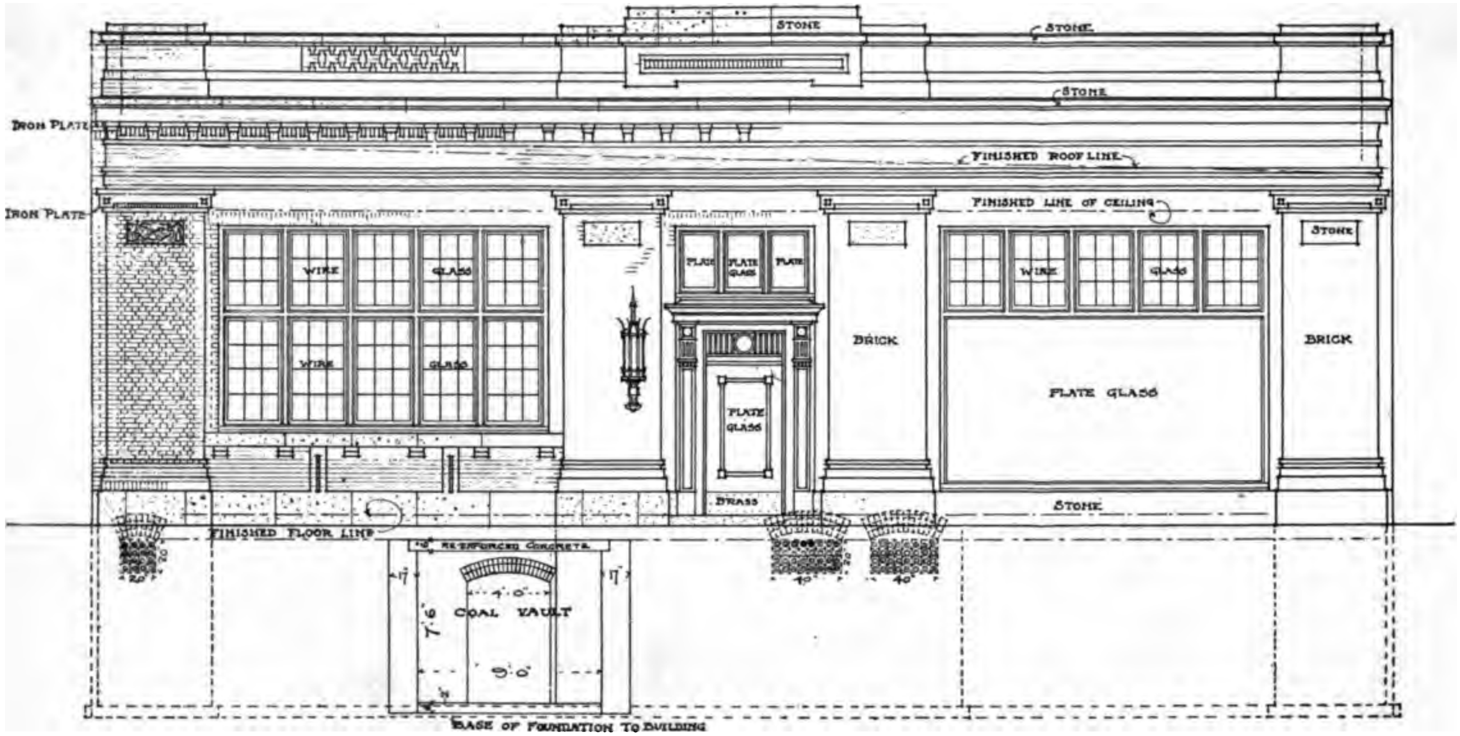
Do not use a bright light against a dark background.

Do not use local lighting alone; provide for a general illumination and then add local lighting as needed.

Use care in the selection of reflectors. Modern globes and reflectors are scientifically designed for given conditions and should be used as planned by their makers.

Light walls and lightly tinted shades are preferred.

Most work can be carried on with an illumination of from 2 to 3 foot candles Fine-print reading and sewing require perhaps 5 foot candles. From 7 to 10 foot candles is ample for drafting, engraving, etc.



WEST SIDE BUILDING FOR THE CLEVELAND ELECTRIC ILLUMINATING COMPANY, CLEVELAND, OHIO
Watterson and Schneider, Architects, Cleveland, Ohio
For exterior and details see pages 234 and 266

LIGHTING OF PUBLIC HALLS, OFFICES, ETC.

Variations from Residence Problem. Lighting of public halls and other large interiors differs from the illumination of residences in that there is usually less reflected light; and, again, the distance of the light sources from the plane of illumination is generally greater, if an artistic arrangement of the lights is planned. This in turn reduces the direct illumination. The primary object is, however, as in residence lighting, to produce a fairly uniform ground illumination and to superimpose a stronger illumination where necessary. An illumination of .5 foot candle for the ground illumination may be taken as a minimum.

Use of Larger Units. In the lighting of large rooms it is permissible to use larger light units, such as arc lamps and high candle-power incandescent units, while for factory lighting and drafting rooms, where the color of the light is not so essential, the Cooper-Hewitt lamp is being employed. High candle-power reflector lamps, such as the tungsten lamp, are being used to a large extent for offices and drafting rooms.

Choice of Type of Unit. The choice of the type of lamp depends on the nature of the work. Where the light must be steady, incandescent lamps are to be preferred to the arc or vapor lamps, though the latter are often the more efficient. When arcs are used, they must be carefully shaded so as to diffuse the light—doing away with the strong shadows due to portions of the lamp mechanism—and to reduce the intrinsic brightness. Such shading will be taken up under the heading "Shades and Reflectors". Arcs are sometimes preferable to incandescent lamps when colored objects are to be illuminated, as in stores and display windows, but the color of the tungsten lamp is a great improvement over the carbon lamps previously used.

Location of Lights. In locating lamps for this class of lighting, much depends on the nature of the building and on the degree of economy to be observed. For preliminary determination of the location of groups, or the illumination when certain arrangement of the units is assumed, the principles outlined under "Residence Lighting" may be applied. It has been found that actual measurements show results approximating closely such calculated values.

Arcs. When arcs are used they should be placed fairly high—20 to 25 feet when used for general illumination and when the ceilings are high. They should be supplied with reflectors so as to utilize the light ordinarily thrown upwards. When used for drafting-room work, they should be suspended from 12 to 15 feet above the floor, and special care must be taken to diffuse the light.

Incandescents. Incandescent lamps may be arranged in groups, either as side lights or mounted on chandeliers, or they may be arranged as a frieze running around the room a few feet below the ceiling. The last named arrangement of lights is one that may be made artistic, but it is uneconomical and when used should serve for the ground illumination only. Reflector lights may be used for this style of work and the lights may be entirely concealed from view, the reflecting property of the walls being utilized for distributing the light where needed.

Ceiling Lights. Ceiling lights should preferably be supplied with reflectors, especially when the ceilings are high.

Indirect Lighting. Indirect lighting is employed to some extent. By indirect lighting we mean a system of illumination in which the light sources are concealed and the light from them is reflected to the room by the walls, or ceilings, or other surfaces; or in which the light sources are placed above a diffusing panel. In the latter case the diffusing plate appears to be the source of light. In some cases the walls themselves are shaped and constructed so as to form the reflectors for the light units (cove lighting), but in others all of the reflecting surfaces, except the side walls and ceiling, are made portions of the lamp fixtures.

Semi-Indirect Lighting. Semi-indirect fixtures are now available. These allow a portion of the light to be diffused and thrown directly on the plane to be illuminated but a large portion of the light is thrown to the ceiling, or to a special reflector taking the place of the ceiling, and from there reflected to the points where the light is required. Fixtures of this nature will be illustrated in the section on shades and reflectors. The following points may be noted when considering direct, semi-indirect, and indirect systems of lighting:

Direct vs. Indirect Lighting. Direct systems are usually the most economical; semi-indirect next; and indirect systems the least economical for a given illumination. The matter of uniform illumination follows the reverse order, direct lighting giving the least uniform effects. The disadvantage of the indirect systems comes from the loss of light through the agency of the required reflecting surfaces. There is also a possibility in indirect systems of lighting of too uniform and too shadowless an illumination, the effect of which is very trying on the eyes. Experiments show that a system using about 15 per cent of the light as coming directly from the light source is more satisfactory than totally indirect systems for the average installation.

For indirect systems the ceilings should be very light in color; with clean white calcimine ceilings the coefficient of reflection will vary from 73 to 78 per cent, depending upon the angle at which the light strikes the ceiling, and the condition of the surface, whether rough or smooth. Fig. 49 shows a distribution curve for a light unit which is considered as ideal for semi-indirect lighting. Distribution curves as obtained in practice will be illustrated in the section covering shades and reflectors.

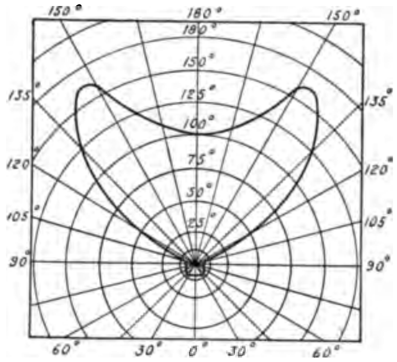


Fig. 49. Prototype Curve for Semi-Indirect Lighting. Scale 100 Unit Directly Upward

Methods of Calculating Illumination. The methods of calculating illumination or of determining the lamps required to give a certain illumination are not different from those already outlined in connection with residence lighting. The point-by-point method may be used, and, with the aid of properly prepared tables of constants, cosines, etc., the work is rendered less burdensome, but the flux-of-light method involves less of numerical calculation and gives excellent results in the majority of cases. Of the various methods of procedure which might be followed in making calculations by the flux-of-light method only one will be illustrated here.

Typical Calculation by Flux-of-Light Method. Assume a room 40′ by 80′, ceiling 15′ high, with medium light walls and ceilings to be lighted with an average intensity of 3 foot candles on a

TABLE XIII

Percentage of Total Lumens from Light Sources Which Are Effective under Different Conditions

Walls	Ceiling	REFLECTORS						
		Bare Lamp	Prismatic Clear	Prismatic Sanded	Steel Porcelain and Aluminum	Opal	White Glass of Light Density	Indirect and Semi-Indirect
		(Percentage of Lumens Effective)						
Light	Light	41	60	51	48	50	48	31
Medium	Light	35	53	47	46	45	44	28
Light	Medium	34	52	47	47	44	43	21
Dark	Light	30	48	43	44	42	40	25
Medium	Medium	30	48	43	45	42	40	19
Dark	Medium	25	45	40	44	40	36	17
Dark	Dark	21	40	36	44	37	33	10

plane of illumination 2½ feet from the floor. There will be required 3×40×80, or 9600 effective lumens. The relation between effective lumens and total lumens of light sources must next be known in order that we may find the total lumens to be given by all of the lamps. Table XIII gives very useful data in this connection (Mazda lamps assumed).

Likewise, in order to get the total candle-power rating of our required lamps, we must know the total lumens given by the different sizes of units. These values are given in Table XIV.

TABLE XIV

Total Lumens, Average, for Mazda Lamps, Based on Lamp Life of 1000 Hours

Rating	Total Lumens, Average
25	189
40	323
60	505
100	842
150	1262
250	2195
400	3512
500	4390

A reflector, say of the clear prismatic type, must first be assumed; then from Table XIII we see that for such a reflector with medium walls and ceilings, only 48 per cent of the total

TABLE XV

Required Intensity of Illumination

Place to be Lighted	Foot Candles Required
Auditoriums, theaters	1 — 3
Bookkeeping rooms	3 — 5
Corridors, halls	.5 — 1
Depots, assembly halls, and churches	.75— 1.5
Drafting rooms	5 — 10
Desk lighting	2 — 5
Engraving rooms	5 — 10
Factories, general, where individual drops are used	2 — 3
Factories, complete, no individual drops	4 — 5
Hotel halls	1 — 1.5
Hotel rooms	2 — 3
Offices (waiting rooms)	1.25— 2.5
Offices (private)	2 — 3
Offices (general)	3 — 4
Offices (where desk lights are used)	1.5 — 2.5
Postoffices	2 — 5
Reading rooms	1 — 3
Residences	1 — 3
Stores (light goods)	2 — 3.5
Stores (dry goods)	4 — 6
Stores (clothing)	4 — 7
Store windows	5 — 20
School rooms	2 — 3
Saloons, cafes, depending on effects	2 — 5
Stations (waiting rooms)	1.5 — 2.5
Train sheds	1.5 — 2
Warehouses	1.5 — 2

lumens are effective; therefore the total lumens must be the required lumens, 9600, divided by 0.48, or 20,000 lumens. By dividing the total of 20,000 by the total lumens of each size of lamp we can get the required number of lamps of that rating which will be required.

For uniform illumination a large number of small units should be used, but local conditions and first cost of installation are important points; and the remainder of this problem will be considered on the assumption that 16 outlets are provided, each fitted with a 150 c. p. unit, and that the outlets are uniformly spaced, the distance between the lamps being 14 feet. Of the prismatic reflector selected there are three types and the type of reflector and the proper mounting height remain to be determined. The ratio of mounting height to distance between lamps is given for the three types of reflector as follows: extensive, 1–2; intensive, 4–5; focusing,

TABLE XVI

Cooper-Hewitt Lamps

Service	Height of Lamp	C. P. of Unit	Av. Area per Lamp in Square Feet
Foundry	10–15 ft.	300	900
Foundry	20–25 ft.	700	2250
Machine shop	10–15 ft.	300	500
Erecting shop	20–30 ft.	700	1250
Drafting room	15 ft.	300	300
Drafting room	20 ft.	700	400
Offices	10–15 ft.	300	400
Offices	20–25 ft.	700	750
Ordinary labor	10–15 ft.	300	1100
Ordinary labor	20–25 ft.	700	2750

4–3. Extensive reflectors would be mounted 9.5 feet from the floor, which might perhaps be too low. Focusing reflectors could not be used to advantage and intensive reflectors should be mounted 13½ feet above the floor; hence the intensive type of reflector works out to the best advantage for our assumed installation.

Required Illumination for Different Locations. As a guide to good illumination values to be assumed for different types of interiors, the following table, Table XV, may be used.

In general, the greater the candle-power of the unit used the higher the units must be mounted to give good lighting effects. For illuminating interiors with arc lamps, the specific distribution curve of the unit—curves of the form shown in connection with the section on arc lamps—should be known and the point-by-point method of calculation can be used, or the number of lumens within the useful angle can be calculated by means of the Rosseau diagram, p. 124 and the flux-of-light method p.p. 62 and 69. Table XVI gives some useful information covering the mercury vapor lamp and Table XVII is a guide to the use of ordinary arc lamps. Reference should be made to Table IX for a comparison of ordinary arcs with the newer types.

In factory and drafting-room lighting, the lamps must be arranged to give a strong light where most needed, and located to prevent such shadows as would interfere with the work.

Special Cases. If space permitted, the details of lighting systems covering rooms used for a wide variety of purposes might

TABLE XVII

Lighting Data for Arc Lamps

Place Lighted	Clothing Store	Weave Room	Erecting Room	Machine Shop	Drafting Room	Drafting Room	Ship Shed	Cataloging Dept.	Jewelry Store
No. of sq.ft. of space lighted	4000	14400	281600	42250	6275	5690	69000	4136	4000
No. lamps used..........	12	50	200	42	27	24	50	17	6
Circuit..................	A. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult.	A. C. Series	D. C. Mult.	D. C. Mult.	D. C. Mult.	D. C. Mult
Cycles..................	60	.....	.....	.....	60	.....	.....	.....	.....
Volts, line..............	104	110	120	120	.....	120	220	110	110
Amperes...............	6	3¼	6.2	6.2	7.5	4	6	4½	5
Volts at arc.............	72	75	80	80	72	80	80	80	80
Power factor of lamp.....	.69	.....	.....	.....	.86	.....	.....	.....	.....
Watts per lamp..........	430	357	744	744	490	480	660	495	550
Watts per sq. ft. (term.)...	1.29	1.24	.53	.74	2.11	2.02	.478	2.03	.825
Kw. at term. (whole installation)...............	5.16	17.8	148.8	31.25	13.22	11.52	33	8.42	3.3
Kw. at arc (whole installation).................	4.62	12.28	99.2	20.8	12.42	7.68	24	6.12	2.4
Sq. ft. lighted per lamp...	333	288	1408	1006	232	237	1380	243	667
Sq. ft. lighted per amp....	55.6	88.6	227	162	31	59.2	230	54.1	133.5
Enclosing globe..........	Opal.		Opal.	Opal.	Opal.	Opal.		Opal.	Opal.
Height and style of ceiling	12′ White Steel	Saw Toothed	Trussed	Trussed	12′ white	Trussed	160′ Trussed	13′ 9″ Maroon	16′ 10″ White
Reflector system used.....	Concentric Diffuser	Adjust. Diffuser	9″ Mirror	9″ Mirror	Concentric Diffuser	16 Adj. Dif. 8 Con. Dif.	12″ Mirror	Concentric Diffuser	Concentric Diffuser
Height of arc from floor...	9′-6″	12′ to 15′	46′	47′	9′	15′	150′	10′-7″	13′-2″
Distance between lamps...	14′ to 18′	24′	32′ to 38′	30′-9″	15′	12′ to 25′	17′ to 20′	14′ to 18′	16′ to 25′

be included. Many of the problems that come up can be satisfactorily met by one of several possible installations and the lighting of interiors is, as a whole, an art as well as a science. The reader is referred to the details of good lighting systems, as they appear from time to time in the technical press, for a more intimate knowledge of the manner in which the principles, as given here, are applied to everyday practice.

Theater lighting becomes a special problem, as does show window and sign lighting, as well as all forms of spectacular lighting; all are problems for which it is difficult to lay down any special rules other than the general ones covering illumination, as they have already been given.

STREET LIGHTING

Nature of Problem. In studying the lighting of streets and parks, we find that, except in special cases, such as narrow streets and high buildings, there is no reflected light which aids the illumination aside from that due to special shades or reflectors on the lamp itself. Such reflectors are necessary if the light ordinarily thrown above the horizontal plane is to be utilized.

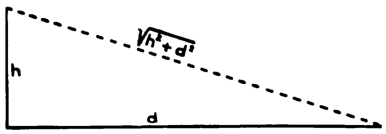


Fig. 50. Diagram for Calculating Street Light Illumination

In calculating the illumination due to any type of lamp at a given point it is necessary to know the distribution curve of the lamp used and the distance to the point illuminated. The approximate illumination of a plane normal to the rays of light is given by the formula

$$I=\frac{c.p.}{h^2+d^2}$$

when I is illumination in foot candles; $c.\,p.$ is candle-power of the unit, determined from the distribution curve of the lamp; h is distance the lamp is mounted above the ground, in feet; and d is distance from the base of the pole supporting the lamp to the point where the illumination is being considered, Fig. 50.

While this will give the illumination in foot candles, the nature of the lighting cannot be decided from this alone, but the total amount of light must also be considered. Thus, a street lighted with powerful units and giving a minimum illumination of .05 foot candles would be considered better illuminated than one having smaller units so distributed as to give the same minimum value.

Ideal and Actual Distribution Curves. Since a uniform distribution of light is desirable, for economic reasons, the ideal distribution curve of a lamp for street lighting would be a curve which shows a low value of candle-power thrown directly downward, but with the candle-power increasing as we approach the horizontal. Such an ideal distribution curve is shown in Fig. 51.

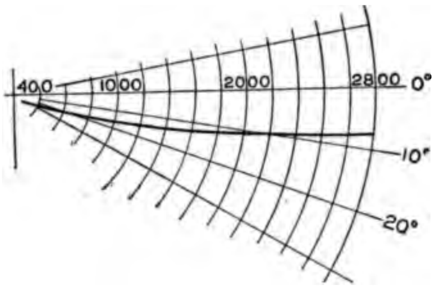


Fig. 51. Ideal Distribution Curve for a Street Light

Actual distribution curves taken from commercial arc lamps are shown in connection with the arc lamp described in the section on this subject. As illustrative of the use of such curves Figs. 52 and 53 are included.

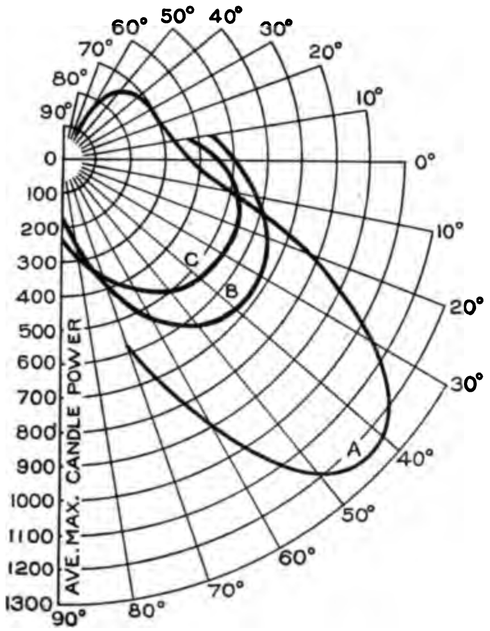


Fig. 52. Distribution Curves for Commercial Arc Lamps Used in Street Lighting

Curve A shows distribution curve for a 9.6-ampere, open direct-current arc.

Curve B shows distribution curve for a 6.6-ampere, d. c. enclosed arc.

Curve C shows distribution curve for a 7.5-ampere, a. c. enclosed arc.

Globes used with B and C are opal inner globes, clear outer globes.

Globes used with A are clear outer globes.

A street reflector was used with the enclosed arcs.

Illumination Curves. A series of curves known as "illumination curves" may be readily calculated, showing the illumination in foot candles at a given distance from the foot of the pole supporting the lamp. Illumination curves corresponding to the distribution curves in Fig. 52 are given in Fig. 53 where *A′*, *B′*, and *C′* correspond to *A*, *B*, and *C* in Fig. 52. These curves correspond to actual readings taken with commercial lamps. Similar curves for incandescent lamps fitted with suitable reflectors are shown in Fig. 54.

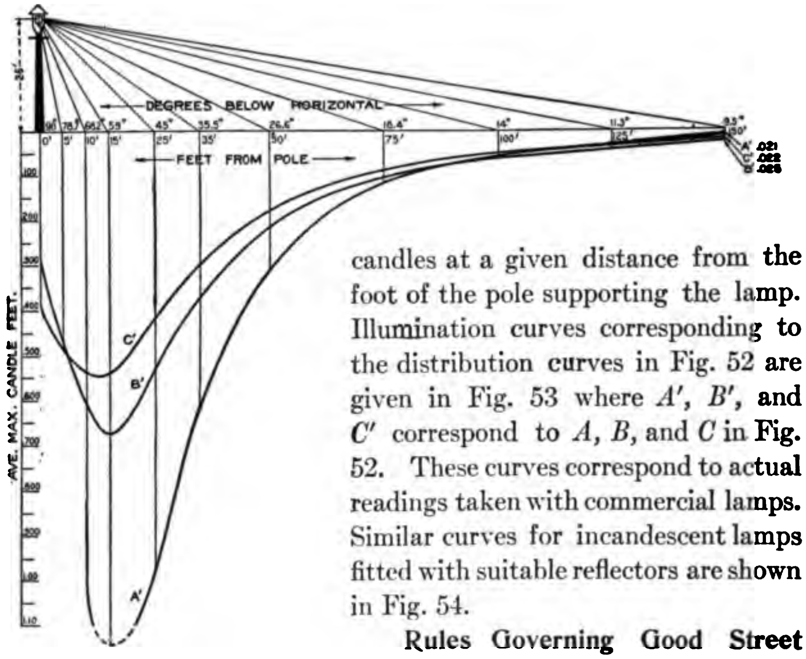


Fig. 53. Illumination Curves Drawn from Data Given in Fig. 52

Rules Governing Good Street Lighting. The principal considerations in street lighting other than ornamental street lighting are:

A sufficient amount of light must be supplied and distributed so as to give a fairly uniform distribution.

Lamps should have as low an intrinsic brilliancy as is practical—all questions, including economy, considered—and they should be so located that any glare will not interfere with ordinary vision.

Ordinarily the maximum amount of light should be given off in a direction about 20 degrees below the horizontal.

The light should be steady, as flickering is always objectionable.

The light should be well diffused so as to avoid deep shadows.

The light sources should be mounted fairly high and the greater the candle-power of the unit the higher the lamp should be mounted.

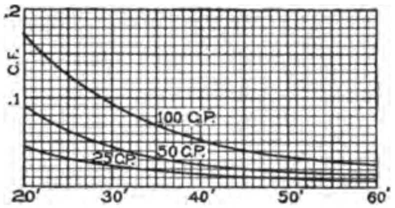


Fig. 54. Illumination Curves for Street Incandescent Lamps

Amount of Illumination for Streets. We may consider the amount of illumination considered as essential for the streets in the different sections of a city as follows:

Principal Business Streets. Principal business streets require illumination of from 0.25 to 1.00 foot candle, as uniform as possible; flaming arc lights, luminous arc lights, and incandescent clusters are now in use in the better systems.

Cross Streets and Boulevards. Cross streets and boulevards require from 0.1 to 0.5 foot candles. If they are free from shade trees, arc lights mounted fairly high may be used; if shaded, smaller units in the way of incandescent lamps mounted at a moderate height give much better results.

Residence Street. On residence streets, the illumination should not be high but all crossings should be well illuminated and incandescent systems, spacing lamps about the usual distance between line poles, are ordinarily installed for these streets.

Outlying Districts. In outlying districts the lighting depends upon the amount of money which is to be used for the purpose and it generally takes the form of incandescent units mounted at important points, such as street crossings. No definite rules can be laid down.

General Specifications. In order to determine what type or types of lamps and the number and spacing of each, which will be required for a given or assumed minimum value of illumination, Table XVIII is given. This table was prepared from experimental work by Messrs. Bryant and Hake at the University of Illinois.

Ornamental Street Lighting. Within the last few years the matter of street lighting has received more attention than formerly and the result has been to introduce more ornamental effects in connection with the systems. These ornamental effects take the form of more artistic supports for the light sources; special coloring of the lights; globes and shades designed to make a better appearance by day as well as by night, etc. For the business streets these ornamental systems provide for a brilliant illumination, at least for a few hours in the early evening, and the tendency is toward higher illumination values along the boulevards where the ornamental features are introduced. The more brilliant lighting from the ornamental systems when installed in the business streets has led to the

TABLE XVIII

Horizontal Distribution at Street Surface for Different Heights and Spacings

	Spacing Feet	h Feet	Distance—Feet								
			0	50	100	150	200	250	300	350	400
6.6 Amp. D. C. Enclosed	800	25	.36	.075	.011	.0034	.0014	.0007	.0004	.0004	.0004
	400	25	.36	.075	.011	.04	.003	.004	.011	.075	.36
	200	25	.372	.082	.023	.082	.372	.082	.023	.082	.372
	800	40	.14	.079	.0168	.0054	.0022	.0012	.0007	.0006	.0006
	400	40	.14	.08	.017	.0066	.0044	.0066	.017	.08	.14
	200	40	.142	.085	.034	.085	.142	.085	.034	.085	.142
7.5 Amp. A. C. Enclosed	800	25	.336	.038	.005	.0019	.0008	.0004	.0003	.0002	.0001
	400	25	.336	.038	.0053	.0023	.0016	.0023	.0053	.038	.336
	200	25	.34	.05	.012	.05	.34	.05	.012	.05	.34
	800	40	.132	.05	.0096	.003	.0013	.0006	.0004	.0003	.0002
	400	40	.132	.05	.011	.0035	.0026	.0035	.011	.05	.132
	200	40	.135	.10	.022	.10	.135	.10	.022	.10	.135
6.6 Amp. D. C. Magnetite	800	25	.80	.225	.034	.0111	.0046	.0024	.0013	.001	.001
	400	25	.80	.226	.035	.0135	.0092	.0135	.035	.226	.80
	200	25	.85	.238	.069	.238	.85	.238	.069	.235	.85
	800	40	.315	.205	.047	.0163	.0073	.0039	.0022	.002	.0016
	400	40	.316	.206	.049	.020	.014	.020	.049	.206	.316
	200	40	.329	.225	.096	.225	.329	.225	.096	.225	.329
4.0 Amp. D. C. Magnetite	800	25	.56	.095	.016	.005	.002	.001	.0016	.0006	.0005
	400	25	.56	.095	.016	.006	.004	.006	.016	.095	.56
	200	25	.564	.101	.033	.101	.564	.101	.033	.101	.564
	800	40	.219	.092	.022	.0077	.0033	.0018	.001	.0009	.0008
	400	40	.219	.092	.044	.0095	.0066	.0095	.044	.092	.219
	200	40	.222	.094	.044	.094	.222	.094	.044	.094	.222
9.6 Amp. D. C. Open	800	25	.08	.133	.013	.0035	.0014	.0007	.0004	.0003	.0003
	400	25	.08	.133	.013	.042	.0028	.042	.013	.133	.08
	200	25	.081	.136	.026	.136	.081	.136	.026	.136	.081
	800	40	.031	.185	.026	.006	.002	.001	.0007	.0006	.0005
	400	40	.031	.185	.026	.007	.004	.007	.026	.185	.031
	200	40	.035	.192	.053	.192	.035	.192	.053	.192	.035
Long Burning Flame Vertical	800	25	1.26	.243	.040	.0132	.0059	.0031	.002	.0016	.0014
	400	25	1.26	.244	.042	.0163	.012	.0163	.042	.244	1.26
	200	25	1.27	.261	.084	.261	1.27	.261	.084	.261	1.27
	800	40	.475	.204	.054	.0193	.0085	.0047	.0029	.0023	.0022
	400	40	.476	.206	.057	.024	.017	.024	.057	.206	.476
	200	40	.486	.230	.114	.230	.486	.230	.114	.230	.486
Flame Arc Inclined	800	25	3.81	.265	.034	.010	.004	.002	.001	.001	.001
	400	25	3.81	.266	.035	.012	.008	.012	.035	.266	3.81
	200	25	3.82	.276	.07	.276	3.82	.276	.07	.276	3.82
	800	40	1.49	.32	.055	.0165	.0064	.0032	.0021	.0017	.0016
	400	40	1.49	.32	.057	.0168	.0128	.0168	.057	.32	1.49
	200	40	1.50	.34	.112	.34	1.50	.34	.112	.34	1.50
6.6 Amp. A. C. Enclosed	800	25	.28	.032	.0044	.0016	.0007	.0003			
	400	25	.28	.032	.0044	.0016	.0014	.0016	.0044	.032	.28
	200	25	.28	.035	.009	.035	.28	.035	.009	.035	.28
	800	40	.11	.042	.008	.0024	.0011	.0005	.0003		
	400	40	.11	.042	.008	.003	.0022	.003	.008	.042	.11
	200	40	.11	.045	.016	.045	.11	.045	.016	.045	.11
350 C. P. Tungsten	800	25	.37	.063	.0095	.003	.0012	.0006	.0004	.0002	.0002
	400	25	.37	.032	.01	.004	.0024	.004	.01	.032	.37
	200	25	.37	.038	.025	.038	.37	.038	.025	.038	.37
200 C. P. Tungsten	400	20	.362	.035	.011	.005	.003	.005	.011	.035	.362
	200	20	.365	.04	.023	.04	.365	.04	.023	.04	.365
	d	h	0	25	50	75	100	125	150	175	200
100 C. P. Tungsten	200	20	.181	.078	.015	.0068	.005	.068	.018	.078	.181
	100	20	.183	.084	.034	.084	.183	.084	.034	.084	.183
60 C. P. Tungsten	200	20	.11	.046	.01	.004	.003	.004	.01	.046	.11
	100	20	.11	.052	.021	.052	.11	.052	.021	.052	.11
32 C. P. Tungsten	200	20	.06	.024	.005	.002	.002	.002	.005	.024	.06
	100	20	.09	.028	.010	.028	.06	.028	.010	.028	.06

introduction of the term "White-Way Lighting," but this term applies more specifically to the incandescent lamp systems than to the systems using ornamental arcs.

Ornamental Standards Most Used. A small amount of ornamental lighting is done by means of arches overhanging the streets and studded with small incandescent lamp units, but the effect is not always what is desired and the more common systems use ornamental standards. These standards may be of cast iron; steel pipe with cast-iron fittings; or occasionally bronze for some special standards; and the other extreme, concrete, where the first cost is a considerable item. These supports may be fitted with one or two arc lamps or with incandescent lamps numbering from one to five, the candle-power of the individual units depending upon the amount of illumination and the display desired. For some special effects several highly colored flaming arcs have been mounted upon one standard and, in other instances, units of extremely high candle-power have been mounted very high above the street or the area to be illuminated.

Arrangements for Turning Off Part of Lights. The arc lighting systems are connected to a series system of distribution but the incandescent units in the business districts, where they are placed close together, are more commonly supplied from a constant potential system, either two- or three-wire, and in this case the current is turned on and off automatically by means of a time clock; it may be controlled from the station by special devices; or it may be turned on and off by a patrolman. In systems using clusters of three or five incandescent lamps it is not uncommon to arrange for turning off all but one unit in each cluster after the early hours of the evening and leaving but one unit burning for the remainder of the night.

Since the high-efficiency nitrogen-filled lamp can as yet be obtained only with filaments of a fairly large diameter, units for multiple operation on 110 volts must be of relatively high candle-power. In order to utilize such a high-efficiency lamp in incandescent ornamental street-lighting systems, a few installations have been made using a transformer in the base of the standard transformer which reduces the distribution voltage, which is usually about 110, to a low value suitable for the particular high-efficiency relatively low candle-power unit installed in the fixtures.

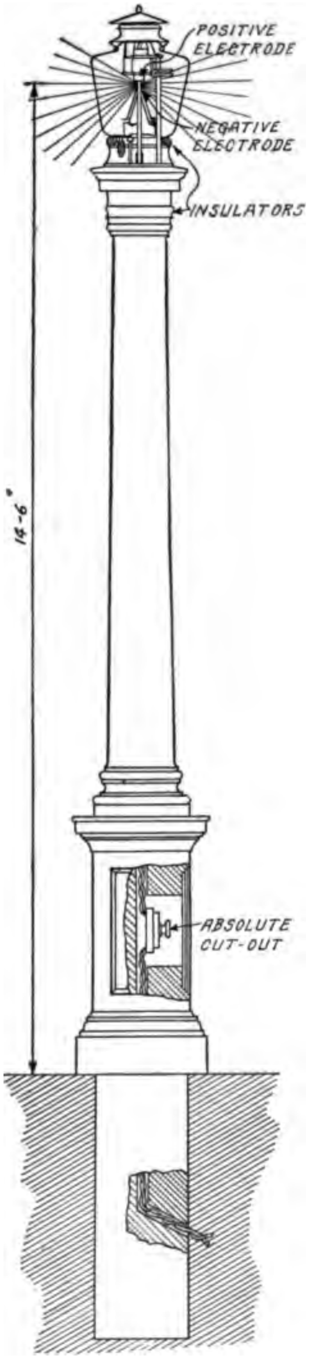


Fig. 55. 6.6-Ampere Luminous Arc Lamp Mounted on Ornamental Pole

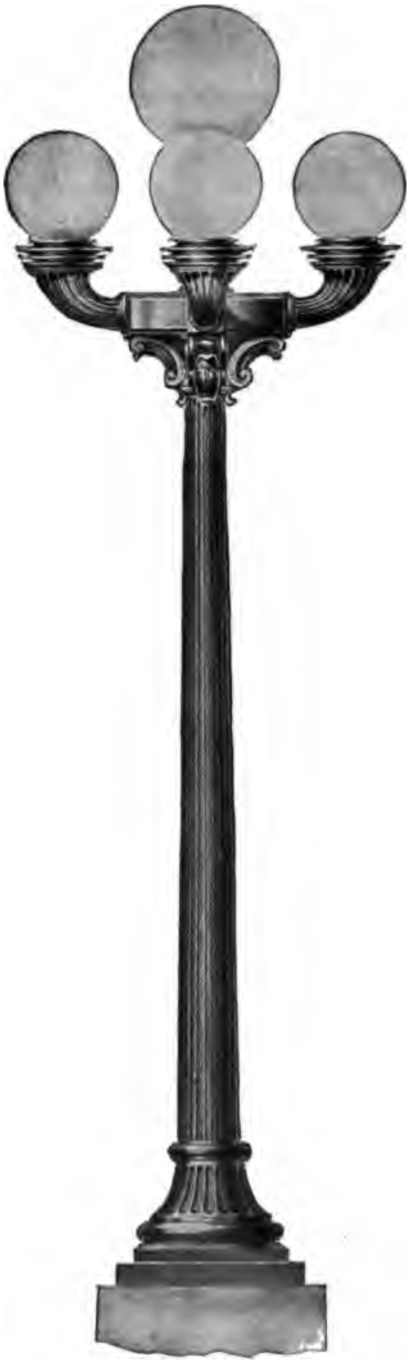


Fig. 56. Ornamental Incandescent Lamp Pole
Courtesy of Smyser-Royer Company

Ornamental street lighting must produce illumination equal to or better than that considered good lighting with the ordinary systems and after that it is a matter of the allowable expense and artistic design as to just what the system will be.

Luminous Arc Specifications. Fig. 55 shows one form of ornamental luminous arc lamp. This lamp and standard is made in more than one size and its use may be outlined as follows: For business streets use a unit of 14 feet 6 inches high, spaced 75 to 100 feet, and staggered, i. e., lamps not placed opposite each other on the street but the unit on one side coming midway between two units on the opposite side. For parkways and boulevards, use a standard 18 feet high unless the foliage interferes. For residence

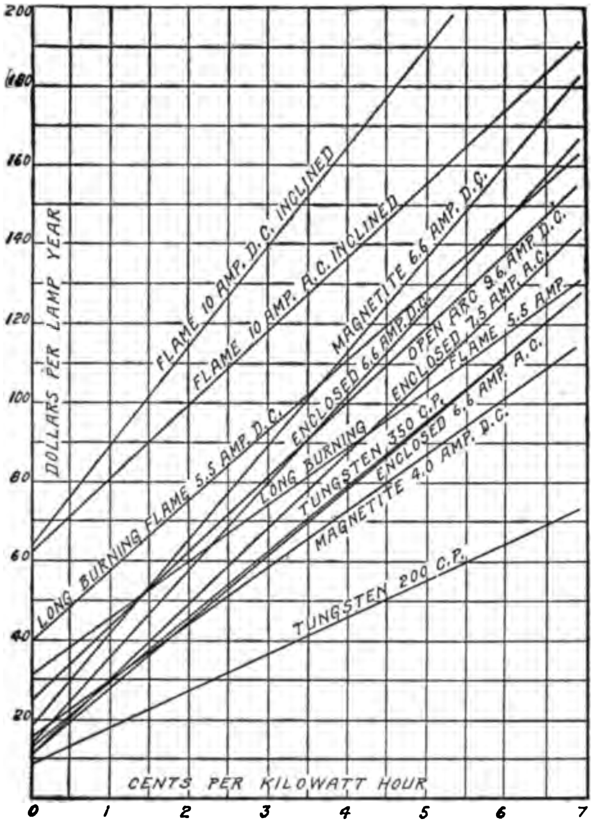


Fig. 57. Curve Showing Annual Operating Cost of Arc Lamps on 4000-Hour Schedule

streets use a unit 12 feet high and space the units about 300 feet apart.

Incandescent Clusters. Fig. 56 illustrates a typical incandescent lamp cluster for business streets. Similar supports may be made for three or for one unit. The clusters are supported from 12 to 15 feet above the curb and with a spacing between standards of from 4 to 6 times the height of the cluster. Standards may be staggered or they may be placed opposite each other on the streets. For a 5-light unit an excellent combination is obtained by using one 100-watt and four 60-watt tungsten lamps per cluster.

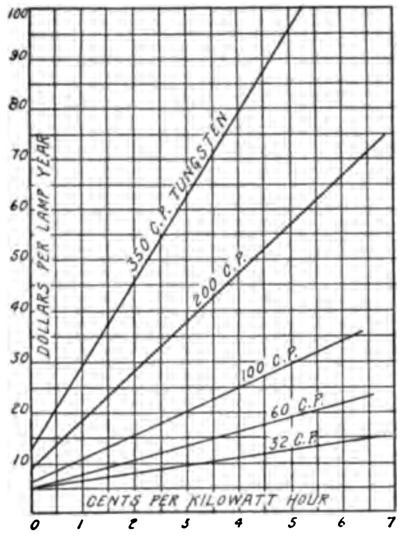


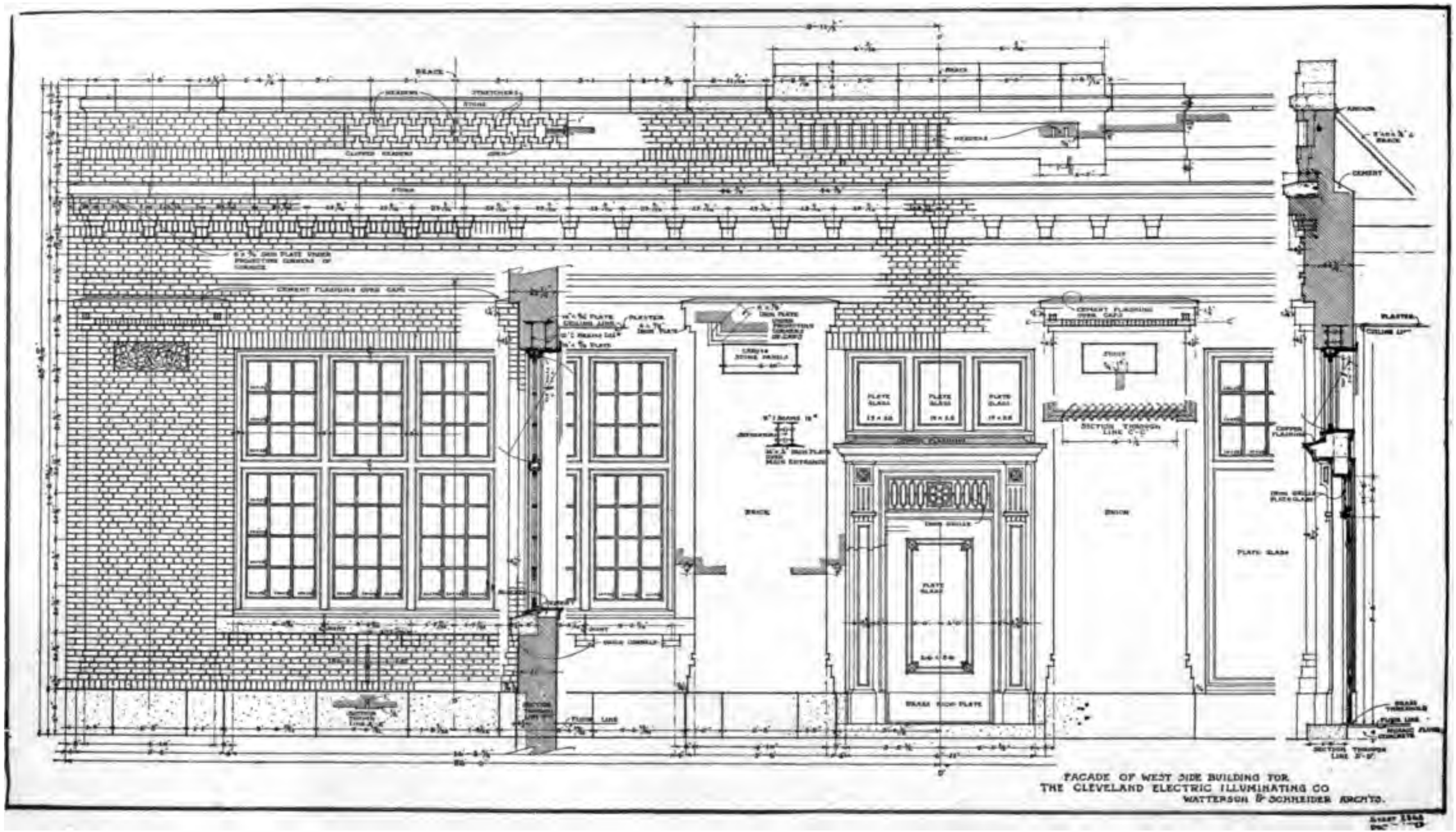
Fig. 58. Curve Showing Annual Operating Cost of Tungsten Lamps on 4000-Hour Schedule

Cost. The cost per standard for incandescent clusters, or for one lamp only, depends upon the material and design of the post, the number and size of the lamp units, the distance they are spaced, etc. For an approximate estimate, the cost of materials only, including cable, regulating devices at the station, etc., will be: five-light pressed-steel standard, total of $96; one-light cast-iron standard, for park service, $44; one-light bracket-fitting, for residence lighting, $15.

Figs. 57 and 58, prepared by Messrs. Bryant and Hake, are on the basis of average cost for labor and materials, interest and depreciation, and for electrical energy at one cent per kilowatt hour.

TRAIN LIGHTING

Of the many specialized fields for electric lighting, probably the lighting of railway cars and trains is as important as any. From about 1850 to about 1875, oil lamps were used almost exclusively for train lighting. From 1875 to 1900 gas occupied the field to the greatest extent. Since 1900 electricity has been introduced more



DETAIL OF WEST SIDE BUILDING FOR THE CLEVELAND ELECTRIC ILLUMINATING COMPANY, CLEVELAND, OHIO

Watterson and Schneider, Architects, Cleveland, Ohio

For exterior and other details see pages 234 and 251 and more extensively so that now nearly all of the first-class trains and a large proportion of the local passenger trains use some form of electric-lighting outfit. A reduction of the fire risk, the ease of control, the excellent quality of the light, the fact that electric lights do not vitiate the air or heat it to the extent that gas or oil lights do, and the possibility of mounting electric lamps where other types of illuminants could not be used are some of the main reasons for the wide introduction of electric lighting for railway trains. Early electric-lighting outfits were not entirely free from interruptions and gas was necessarily retained for use in cases of emergency. Continued improvement in equipment has been made and at present failures are in the neighborhood of one per 1,000,000 miles of operation.

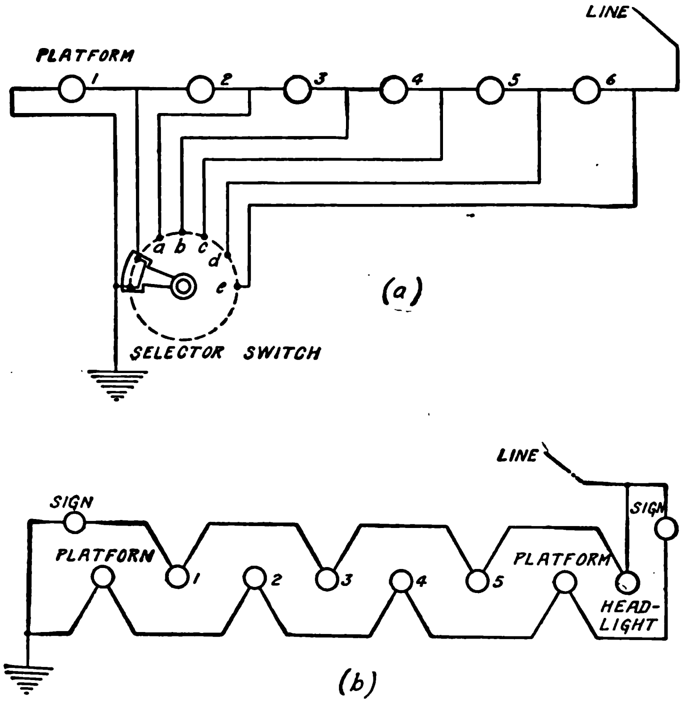


Fig. 59. Wiring Diagrams for Street Car Lamps. (a) For 94-Watt or 56-Watt Tungstens; (b) For Lamps in Two Independent Circuits

Units. The first of the electric car-lighting systems used carbon incandescent lamps which, on account of train vibration and the relatively high voltage then used, had an efficiency of about 4 watts

TABLE XIX

Characteristics of Tungsten-Filament Street-Railway Lamps

Watts	Hor. C. P.	Watts per C. P	Lumens	Life in Hours
23	17.1	1.34	168	2000
36	26.8	1.34	263	2000
56	46.7	1.2	457	2000
94	78.3	1.2	767	2000

per candle-power. With the advent of the higher efficiency incandescent units, each in turn was adapted to train lighting and today the tungsten lamp is standard. The increased efficiency of the lamp has done much to extend the use of electricity for train lighting as the weight and cost of the generating and controlling equipment has been reduced in proportion to the increase in efficiency of the lighting units.

For the lighting of electric cars the units listed in Table XIX are now considered standard. These lamps may be secured for voltages of from 105 to 130, making them adapted, five in series, to line voltages of from 525 to 650. Wiring diagrams for car lighting are shown in Fig. 59.

Table XX gives data covering the present standards for steam train lighting units. The Gem berth-light lamp still has a limited application.

Fixtures and Reflectors. There is considerable leeway in the choice of a suitable fixture and reflector for car lighting; and single-light ceiling fixtures, mounted in one row down the center of the car, single-light ceiling fixtures mounted in two rows, one down either side of the car; and two-light ceiling fixtures, mounted in one row down the center of the car, are all used. Glass reflectors are employed for the majority of the work but metal reflectors are installed in baggage, mail, and express cars, and in other locations where glass reflectors are liable to breakage and appearance is not of first consideration. Semi-indirect units and shades

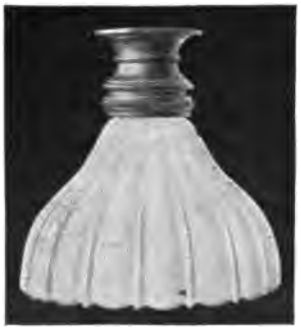


Fig. 60. Typical Electric Car Fixture

TABLE XX

Electric Lamp Units for Steam-Train Lighting

Class	Voltage	Rated Watts	Watts per Mean Horizontal Candle-Power	Mean Horizontal Candle-Power	% Spherical of Mean Horizontal Candle-Power	Total Lumens	Lumens per Watt	Life in Hours
Mazda	25-34 and 50-65	10	1.23	8.0	79.0	79	8.07	1000
		15	1.23	12.0	79.0	119	8.07	1000
		20	1.23	16.0	79.0	159	8.07	1000
		25	1.23	20.0	79.0	199	8.07	1000
		50	1.23	40.0	79.0	397	8.07	1000

Gem Berth-Light Lamp

Class	Voltage	Rated Watts	Watts per Mean Horizontal Candle-Power	Mean Horizontal Candle-Power	% Spherical of Mean Horizontal Candle-Power	Total Lumens	Lumens per Watt	Life in Hours
Gem	28-34	15	2.46	6.1	84.5	65	4.32	300
	57-65	20	2.46	8.1	84.5	86	4.32	300

Straight-Side or Compensator Lamps

Class	Voltage	Rated Watts	Watts per Mean Horizontal Candle-Power	Mean Horizontal Candle-Power	% Spherical of Mean Horizontal Candle-Power	Total Lumens	Lumens per Watt	Life in Hours
Mazda	25-34 and 50-65	10	1.23	8.0	79.0	79	8.07	1000
		15	1.23	12.0	79.0	119	8.07	1000
		20	1.23	16.0	79.0	159	8.07	1000
		25	1.23	20.0	79.0	199	8.07	1000
		40	1.23	32.0	79.0	318	8.07	1000
		50	1.23	40.0	79.0	397	8.07	1000

with special ornamental features are also used. Two things must be considered in selecting fixtures for car lighting: Glare must be reduced to a minimum on account of the comfort of the passengers, and hence bare lamps cannot be used to advantage; and the efficiency of the system is of importance, especially on account of the equipment which must be carried. Because of the necessity of mounting the units relatively low, special precautions are necessary to prevent glare, and the deep bowl type or the indirect type of reflectors are effective in this respect. Fig. 60 illustrates a modern electric car fixture which, when used with 94-watt tungsten lamps and spaced 8 feet and 10 inches apart in a row along the center of the car, gave average illumination at the seats on a plane 37 inches above the floor of 3.72 and 4.32 foot candles at the positions ordinarily occupied by passengers.

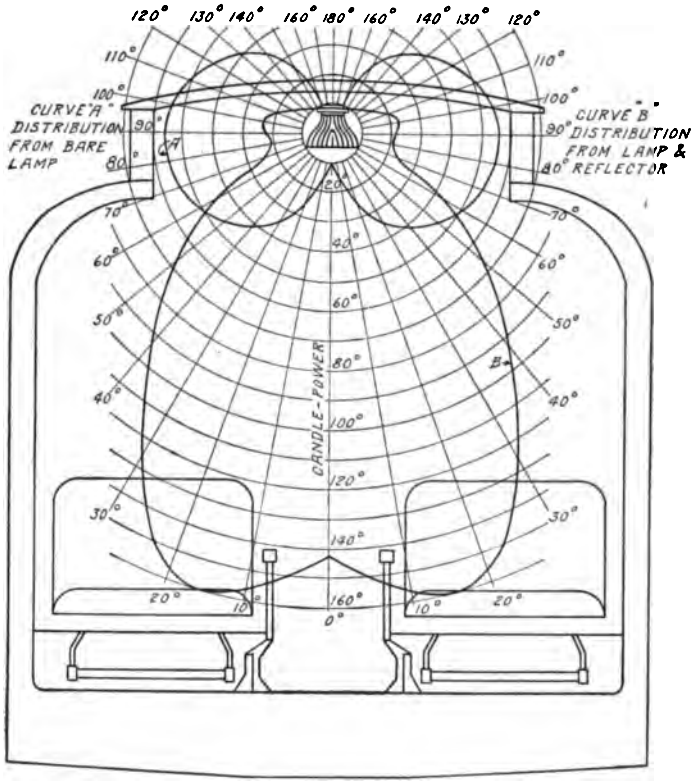


Fig. 61. Distribution Curves Showing Effect of 40-Watt Clear Prismatic Reflector on Light Distribution from 56-Watt Railway Tungsten Lamp

Fig. 61 shows the effect of a suitable reflector for car lighting upon the distribution curve of the bare lamp.

As illustrative of the illumination of steel passenger coaches, the results of a test upon a standard car equipped with 10 single-light center-deck fixtures, each fixture fitted with a 50-watt 60-volt lamp and a deep bowl-shaped clear prismatic reflector, showed an average of 2.6 foot candles at points over the seats and 36 inches above the floor.

Headlights. For headlights on electric cars and locomotives the luminous arc light is used to a considerable extent. This is ordinarily made in 4-ampere and 2-ampere sizes. For street cars there are two methods of producing a dimmer headlight for use on the brightly lighted streets; one is to equip the lamp case with an incandescent lamp, switched on in place of the arc, and the other is to reverse the current through the arc; the light is considerably dimmed by sending the current in the reverse direction. With the development of the helical shape of tungsten filament, incandescent lamps are being used to a greater extent where a powerful headlight is needed. The supply of electricity for electric arc lights for steam locomotives is from a small steam-driven generator mounted on the locomotive.

GENERATOR SYSTEMS FOR TRAIN LIGHTING EQUIPMENT

The results of all of the preliminary experimental work have been to establish three general systems for the supply of electricity for train lighting. These are known as: the straight storage-battery system; the head-end generator system; the axle-generator system.

Straight Storage-Battery System. In the straight storage-battery system, batteries are provided and they must be charged at the terminals. Either the cars must be held over while the batteries are being charged or else there must be provision for the interchange of batteries. For such systems the batteries must have a capacity in excess of the amount of electricity required for the regular run of the cars equipped and suitable charging and exchange stations must be provided. The batteries in general service are rated at about 300 ampere hours and, as ordinarily mounted, the battery is divided into two parts, each part giving 32 volts, the two parts in series furnishing 64 volts. An ampere-hour meter is used as an indication of the state of charge of the battery. Occasionally, such a battery will be operated with its two parts in parallel at 32 volts but standard practice uses the series connection. The batteries are mounted in boxes underneath the car where they are readily accessible for exchange or inspection, and charging plugs are provided for facilitating connections when they are charged at the terminals. The wiring for the lamps is exceedingly simple, the straight parallel connection of the lamps being used. The main advantage of the straight storage-battery system of train lighting is its great simplicity.

Head-End Generator System. For the head-end generator systems, a steam generator, usually driven by a steam turbine, is mounted either in the baggage car or on the locomotive. The steam turbine is supplied with steam from the locomotive boiler at reduced pressure through a flexible steam hose connection and electrical conductors are run throughout the length of the train for the supply of electricity to the lights. Flexible connectors are in use between

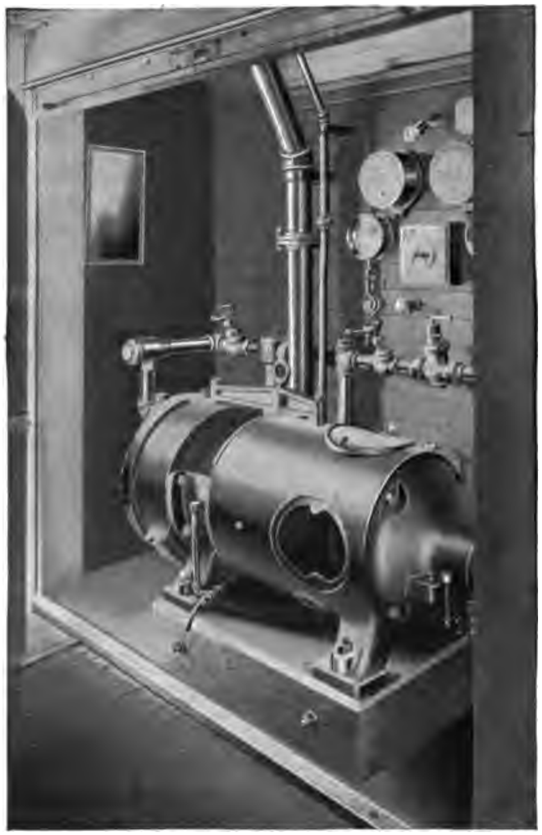


Fig. 62. Steam-Driven Railway Generator Equipment Located in Baggage Car
Courtesy of General Electric Company

cars. Since the cars cannot always be connected to the locomotive or to the baggage car upon which a generator is in operation, a storage battery is still an essential item of the equipment.

Equipment. In general, a head-end generator system requires: a generator, usually steam-turbine-driven, as engine-driven generators produce some vibration (this may be placed in the baggage car or on the locomotive); the necessary indicating and controlling apparatus, placed near the generator; proper train lines and flexible connectors; switches; storage batteries, usually put up in two sections, which sections are mounted underneath the car and connected in series; and some device for maintaining a proper voltage at the lamps. The usual voltage of the system is 64, the same as the straight storage-battery system. It has the disadvantage of not being very flexible and its main application is to through trains which regularly are made up with the same equipment, and this equipment carried for long runs. Taking the equipment up in the same order as enumerated above, the generator is usually of a capacity from 15 to 35 kilowatts, the turbine operating at a steam pressure of 90 to 100 pounds, non-condensing, and the generator rated at 80 volts for the 64-volt system. Fig. 62 illustrates such a generator in position. The usual ammeter, voltmeter, field rheostat, and main switch are supplied in connection with the generator. The usual train line is of 3-0 conductors with flexible connections between cars; and these connections are made so that a reversed polarity on the batteries is not possible.

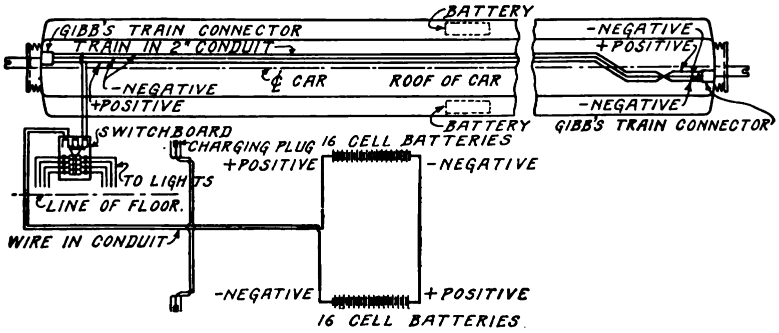


Fig. 63. Diagram of Standard Train Line and Battery Connections as Recommended by the Association of Railway Electrical Engineers

Standard Car-Wiring Diagrams. **Fig. 63 shows a standard car-wiring diagram. A few batteries of 300 ampere-hours capacity may be installed, say three for the whole train, or each car may be equipped with a smaller battery. These batteries do not differ, except possibly in size, from those used with the straight storage-battery system. On some systems no special regulating devices for the control of the voltage on the lamps is installed, and in such cases the lamp voltage is, at times, considerably above normal. When operating the generator at 73 volts, the voltage at the rear car of a seven-car train will be about 66 volts and at times it is desirable to run the generator at 78 volts in order to charge the batteries properly. The better** systems use some form of controlling device, of which there are several available. With these the generators may be operated at the voltage required by the batteries and the lamps still be operated at their normal voltage of 63. Some of these regulators operate upon the same principle as the regulators which will be described later in connection with the axle-generator systems, while in other cases special boosters are installed. Fig. 64 shows a wiring diagram of a system used by the Baltimore and Ohio Railroad, which system has a lamp regulator on each car. Fig. 65 shows the wiring of one type of booster system. Each car is equipped with a motor generator or booster set and a control box for this regulator, both mounted underneath the car. The booster armature is connected in series

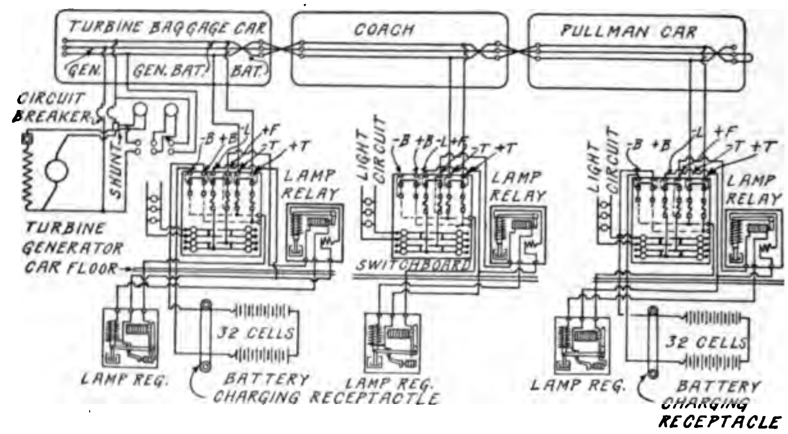


Fig. 64. Wiring Diagram for Baltimore and Ohio Head-End System

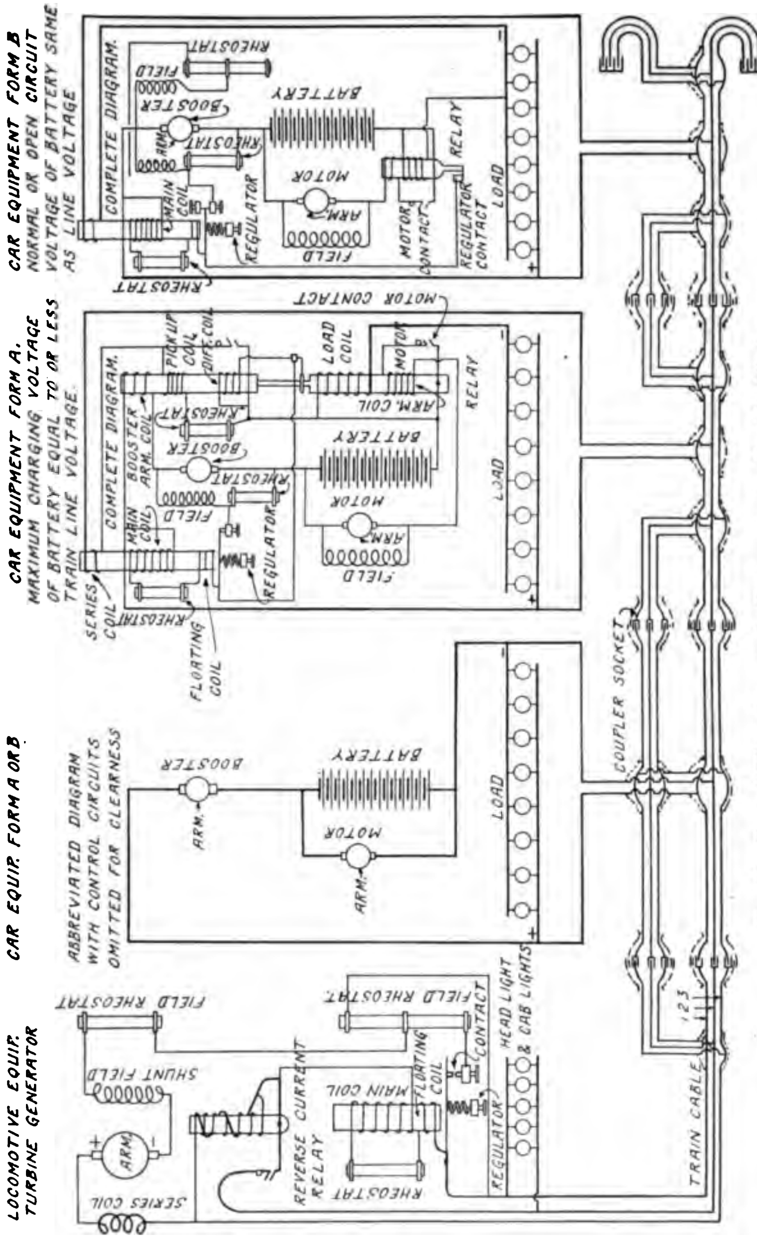


Fig. 65. Typical Wiring Diagram for Turbo-generator Head-End System

with the battery, and the lamps, for all practical purposes, are connected across the train lines. Two forms of regulator are manufactured: Form A, for use when the maximum charging voltage of the battery is equal to or less than the train line voltage, and Form B for use when the open-circuit voltage of the battery is equal to the train line voltage. The action of the regulators is such that, when the train-lighting load is heavy, the battery voltage is lowered, so that it will discharge and help the generator and, when the lamp load is light, the battery voltage will be raised and the battery will be charged.

Axle-Generator System. *Equipment.* The axle-generator system is very commonly employed and this system requires the following general equipment: an axle-driven generator mounted on the trucks with a suitable suspension from the truck frames; a driving mechanism between the generator armature and the axle; a regulator for controlling the voltage and output of the generator, at all train speeds; an automatic switch designed to keep the battery from discharging through the generator; a regulator for controlling the voltage at the lamps; and a battery for supplying the current when the generator is not in use.

Requirements. For an axle-generator system to be successful it should meet the following requirements: The polarity of the generator must remain unchanged with a reversal of the direction of the motion of the car; at all train speeds from the time of the cutting in of the generator to the maximum, the voltage and output of the generator must be kept within practical limits; the generator must be automatically cut in and out of service as the speed of the train rises above or falls below a certain critical value; the transfer of the lights from the battery to the generator and *vice versa* must be accomplished without serious voltage changes on the lamps; the voltage upon the lamps must, at all times, be kept within such limits that the illumination will be satisfactory and the life of the lamps will be reasonable.

In order to accomplish the above, several different systems have been worked out and the essential parts of some of the systems will be considered briefly here:

Mounting of Generator. The general practice is to support the axle generator from the truck frame. "Inside" suspension, i. e., mounting the generator between the axle and the truck-end sill, was first employed but "outside" suspension, placing the generator outside of the truck frames, is preferred on account of the greater accessibility. Of the bottom-pivoted, top-pivoted, parallel-link, and sliding methods of suspending the generator from the suspension framing, the parallel-link method is preferred.

Drive for Generator. The usual drive is by means of a rubber-filled canvas belt running on steel pulleys on the axle and on the generator shaft. A suitable belt tension is provided by means of springs which provide relief to the belt, when this is required on account of the movement of the car axle with respect to the truck frame. Ball bearings are used on some generators.

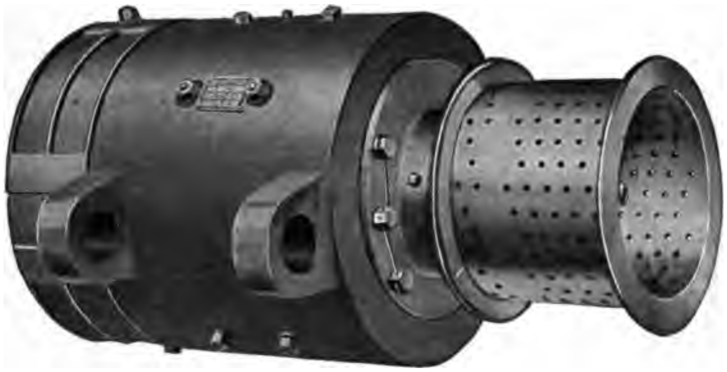


Fig. 66. Belted Train-Lighting Axle Generator
Courtesy of Safety Car Heating and Lighting Company

Generators. Straight shunt-wound generators of the two-pole or multipolar type are in general use but in some of the systems employed abroad a special generator, designed to maintain automatically a constant current irrespective of the speed, is used. The Rosenberg dynamo, designed especially for train lighting, is one type of such a generator but, since its use in the United States is rather limited, it will not be described here. The generator capacity varies from 2 to 4 kilowatts, depending upon the type of car and its lighting arrangements. The usual method of operation is to keep the current output of the generator approximately constant, the battery furnishing the excess energy required when all lamps are burning and the generator charging the battery when the lamp load is not so heavy. Fig. 66 illustrates a train-lighting axle dynamo as made by the Safety Car Heating and Lighting Company.

Reversal of Polarity. In order that the generator may operate with the same polarity upon the train and battery line at all times, it is necessary in most cases that a device for reversing the polarity of the machine with the reverse direction of the motion of the car be provided. Two general schemes are in use: In one, some mechanical device is provided to close a double-throw reversing switch to the proper position; and in the other, the brushes are rotated through 90 electrical degrees, either by the force of friction between the commutator and the brushes or by some other mechanical means.

Automatic Switch. In order that the generator shall be brought into action when the car has reached a certain predetermined speed and that it shall be disconnected from the system and the lamps supplied from the battery alone when the speed falls below this value, some form of automatic switch is required and such a switch may be operated electrically or mechanically. The electrical operation of this switch is preferred.

Generator Regulator. If the generator is to be operated at constant current, irrespective of its speed and irrespective of the lighting load, some regulating device must be used to accomplish this. Many methods are in use and among them may be mentioned: automatic slipping of the belt, the sliding of the armature along the generator shaft, counter compounding, special boosters, armature reaction, and automatic rheostats. Automatic field rheostats appear to be preferred in the American practice. Ordinarily the generator operates at constant-current output but, as the battery charges when the lamp load is light, the generator voltage will have to increase gradually in order to maintain a constant output and, if this were continued indefinitely, the batteries might become badly overcharged. Another function of the control device, then, is to reduce the current output of the generator, after the batteries are fully charged, so that the generator will "float" upon the train line.

Lamp Regulator. If the generator voltage is going to vary some 30 per cent, as is necessary if it is to provide for the proper charging of the battery, then some mechanism is necessary for maintaining a constant voltage on the lamps and this regulator usually consists of a resistance which is automatically switched in and out of the lamp circuit as may be required, Fig. 67. The usual lamp voltage for the axle-generator system is 32.

Operation of Safety Car Lighting and Heating Company Equipment. With all of the necessary devices it is readily seen that there are many different arrangements of the details in use in making up a complete train-lighting system and individual manufacturers put out several different types of equipment adapted to the various needs of the different roads and the different train equipment. To describe all of them would require a very great amount of space, so that details of only one system, the one employing the Type F regulator as manufactured by the Safety Car Lighting and Heating Company, will be given here. Fig. 68 shows the connections of the system and its operation is as follows:

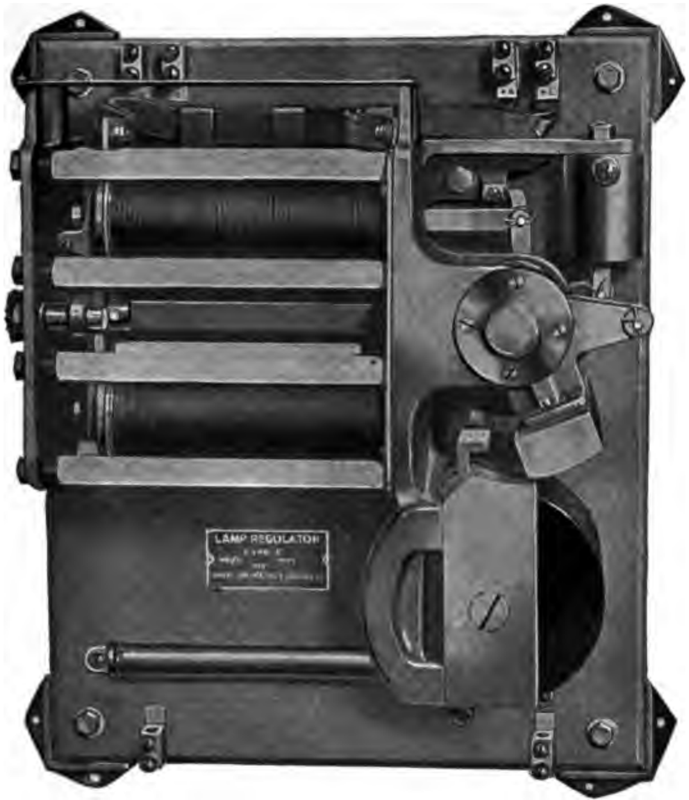


Fig. 67. "Type F" Lamp Regulator Panel
Courtesy of Safety Car Heating and Lighting Company

When the dynamo is at rest the field resistance carbons *C* are tightly compressed by the pull of the spring G_1 so that their resistance is low. As soon as the armature begins to revolve, current flows through the field *F* and builds up a voltage which energizes the lifting coil of the main switch *H*. As soon as this voltage is the same as the battery voltage, the main switch closes, cutting into circuit the series coil of the main switch, which holds the switch firmly closed. Current now flows from the positive dynamo terminal, through the series coil of the main switch *H*, through the series regulating coil *S* to the lamps and storage battery *B*, and back to the negative dynamo terminal.

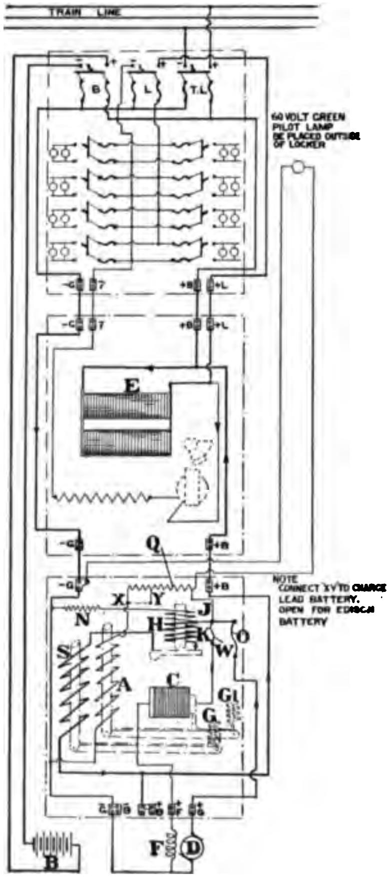

TRAIN LINE
B
L
T.L
60 VOLT GREEN PILOT LAMP BE PLACED OUTSIDE OF LOCKER
-G
7
+B
+L
E
Q
NOTE CONNECT XY TO CHARGE LEAD BATTERY. OPEN FOR EDISON BATTERY
X
Y
J
N
H
K
O
W
S
A
C
G1
G
F
D
B

Fig. 68. Wiring Diagram for Lamp Regulator in Car
Courtesy of Safety Car Heating and Lighting Company

As the train speed increases and the dynamo is able to give its full output, the control is by means of the series coil *S*, provided the full output of the dynamo can be used for charging the storage battery or for the lamps. As the storage battery becomes charged and its voltage rises, the current tapers off so that the full output of the dynamo is no longer required, and the series coil arm moves out of engagement with the voltage coil arm and rests against its stop. The voltage coil *A* then prevents the voltage from rising above the voltage for which the regulator is set.

If a lead battery is charged at a constant voltage of 2.5 per cell, the charge will start at a high rate and automatically taper to nearly zero as the battery becomes full, corresponding to a stop charge.

In a 30-volt equipment having sixteen cells, the battery will be protected from overcharge if the dynamo gives 40 volts and the battery will be charged in the shortest possible time. If, however, the battery is almost discharged and there is a heavy lamp load, the demand on the dynamo would be greater than its safe capacity, so that coil *S* is necessary to limit the current the dynamo can give. The action of the Type "F" dynamo regulator is, therefore, to cause the dynamo to give its full rated capacity at all times if it can be used, and to protect the battery from overcharge as its voltage can never be above 2.5 volts per cell.

The lamp regulator keeps the voltage constant at the lamps by varying in the proper amount the carbon resistance *E*, in series with the lamps. The carbons *E* are compressed by an adjustable spring connected to a link acting through a toggle. The pull of the spring is opposed by the pull of the electromagnet which is connected directly across the lamp mains and is so designed that the armature will stay in any position throughout its stroke when the lamp voltage is right.

When the lamp voltage is high, the magnet becomes stronger and pulls the armature down against the pull of the spring and reduces the pressure upon the carbons *E*, increasing their resistance and bringing the lamp voltage back to normal. If the lamp voltage is low, the magnet becomes weakened and the spring pulls the armature back and, through the toggle, exerts enough pressure on the carbon discs to decrease their resistance and bring the lamp voltage back to normal.

Data Covering Various Types of Equipment. Table XXI gives some comparative data covering the various makes of train-lighting equipment.

SHADES AND REFLECTORS

Lamps, as ordinarily constructed, do not always give a suitable distribution of light, while the intrinsic brightness is often too high for interior lighting. Shades are intended to modify the intensity of the light, while reflectors are used for the purpose of changing its direction. Frequently the two are combined in various ways. Shades are also used for decorative purposes, but, if possible, these should be of such a nature as to aid illumination rather than to reduce its efficiency.

[illegible]	[illegible]	[illegible]									
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
[illegible]	[illegible]		[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Silvertown	Double	Mechanical	Constant current	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]			
Brown-Boveri	Single		Rising voltage if lamps not on	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Dalziel	**Single**		Constant voltage	None required	Differential relay	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]

LIBERTY ENLIGHTENING THE WORLD

Colossal Statue by Bartholdi, Erected on Bedloe's Island, New York Harbor. A Gift of the French People to the American Nation. Dedicated in 1886. Total Height, 305 Feet. Height of Statue without Pedestal, 151 Feet. The Statue Consists of a Trusswork of Iron Beams Enveloped in a Sheathing of Copper Plates Hammered into Shape. Over 200 Tons of Metal was Used in the Construction. The Pedestal, Designed by the Late Richard H Hunt, was Paid for Largely by Popular Subscription in the United States.

TABLE XXI (Continued)

Comparative Data of Various Makes of Electric Train-Lighting Equipment

Makers	Single-or Double-Battery System	Method of Transposing Batteries in Double System	Type Constant Current or Constant Voltage	Pole-Changing Device	Method of Regulation	Method of Adjusting Output	Type of Automatic Switchgear	Voltage Compensation in Lamp Circuit when Charging	Alteration of Compensation when Lamps are Switched	Alteration to Output when Main Lamp Switch is Operated	Overcharge Preventer (Type)
Grob......	Double	Mechanical	Constant voltage	Mechanical	Series excitation armature bucking against regulating battery	....	Mechanical	Lamps on dynamo; battery on booster	None required	Battery charging independent	None required
Buttner....	Single	....	Constant current	None required	Armature reaction	Field resistance	Electrical	Hot wire resistance	Separate hot wire resistance	By field resistance	Adds extra field resistance
Newbold...	Single	....	Constant current	Mechanical	Automatic rheostat	....	Electrical	Resistances	Separate resistance	By extra coil on regulator	....
Gould......	Single	....	Compound	Mechanical	Carbon powder regulator. Series and shunt	....	Electrical	Separate regulator	Separate regulator	....	Shunt coil of regulator
Consolidated	Single	....	Constant current	Mechanical	Automatic rheostat	Adjustment of regulator	Electrical	Automatic resistance	Automatic resistance	None	Adds field resistance
United States	Single	....	Constant current	Brush rocker	Automatic rheostat	Adjustment of regulator	Electrical	Automatic rheostat	Automatic resistance	None	Reduces dynamo voltage
Safety	Single	....	Constant Current	Brush rocker	Automatic rheostat	Adjustment of regulator	Electrical	Automatic rheostat	Automatic rheostat	None	Reduces dynamo output

TABLE XXII

	PER CENT
Clear glass	10
Alabaster glass	15
Opaline glass	20–40
Ground glass	25–30
Opal glass	25–60
Milky glass	30–60
Ground glass	24.4
Opal glass	32.2
Opaline glass	23

A considerable amount of light is absorbed by the material used for the construction of shades. Table XXII shows the approximate amount absorbed by some materials.

Of the great number of styles of shades and reflectors in use, only a few of the more important will be considered here.

Frosted Globes. One of the simplest methods of shading incandescent lamps is by the use of frosted bulbs. These serve to reduce the intrinsic brightness of the lamp and should be freely used for residence lighting when separate shades are not installed. Frosted globes are also used in connection with reflectors for the purpose of diffusing the reflected light. The McCreary shade as shown in Fig. 69, is an example of such a combined shade and reflector. Opal or opalescent enclosing globes are often used for reducing the intrinsic brilliancy and diffusing the light.

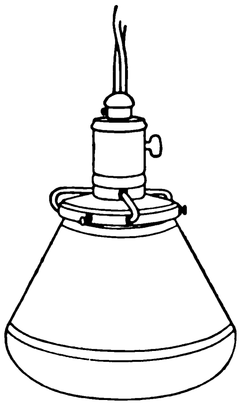


Fig. 69. McCreary Shade

Holophane Globes. Holophane globes are made for both reflecting and diffusing the light and they can be made to bring about almost any desired distribution with but a small amount of absorption of light. These consist of shades of clear glass having horizontal grooves that form surfaces which change the direction of light by refraction or total reflection as is necessary. The diffusion of light is effected by means of deep rounded vertical grooves on the interior surface of the globe. While these globes are of clear glass and absorb an amount of light corresponding to clear glass, the light is so well diffused that the filament of the lamp cannot be seen and the globe appears as if made of some semi-transparent material. The holophane glassware is made in a large variety of artistic designs and for all types of incandescent lamps. By the proper selection of a reflector, the distribution of the light of the unit used may be made that which is best suited to the particular case of lighting in hand. Figs. 14 and 15 give some idea of what can be accomplished by these shades.

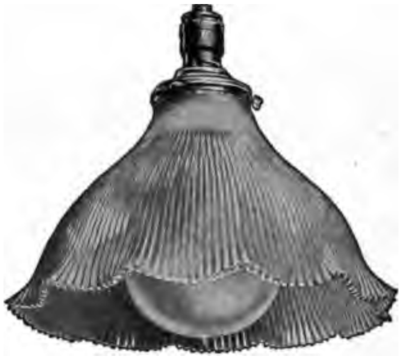


Fig. 70. Typical Prismatic Reflector
Courtesy of National Electric Lamp Association

Changes have been made in the original design of the holophane reflector and the modern type is generally known under the term, "prismatic reflector". The appearance of the prismatic glass reflector is shown in Fig. 70 and for the tungsten lamp it is regularly made in three types: extensive, where the light is widely distributed below the horizontal plane; intensive, where the light is more concentrated in the downward direction but still fairly well distributed; and focusing, where nearly all of the light is thrown directly downward from the lamp. Fig. 71 well illustrates the character of the distribution when these reflectors are used. Clear glass reflectors are very effective if they are properly designed and carefully selected.

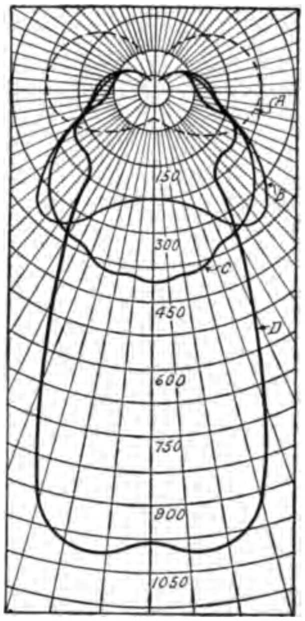
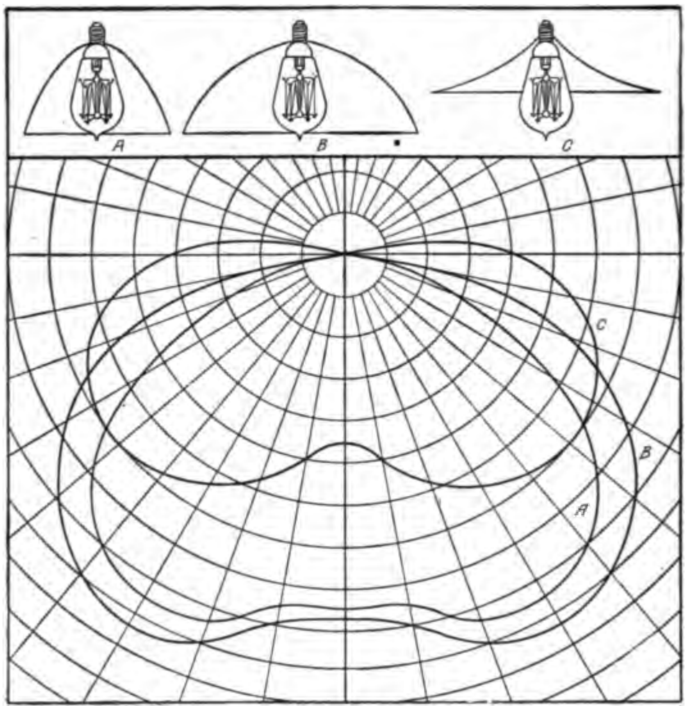


Fig. 71. Photometric Curves for Prismatic Reflectors. *A*-Bowl Frosted Tungsten Lamp; *B*-Same Lamp with Extensive Type Reflector; *C*-Same Lamp with Intensive Reflector; *D*-Same Lamp with Focusing Type Reflector

Metal Reflectors. Glass reflectors are subject to breakage and this is to their disadvantage in certain locations. Metal reflectors have been designed for use where the unit must be more rugged. Metal reflectors may be lined with porcelain enamel, or a bright metallic surface, such as can be secured with the use of aluminum, may be employed for the reflecting medium. Fig. 72 illustrates both the form of these units and the distribution of light from them.



Percentage Light Flux

Unit	A	B	C
Total light from lamp	100.0	100.0	100.0
Light absorbed by reflector	37.0	18.6	14.8
Light in upper hemisphere	0.0	0.0	6.4
Light in lower hemisphere	63.0	81.4	78.8
Light in 60° zone	53.4	59.2	41.3

Fig. 72. Types of Metal Shades and Characteristic Distribution Curves

Decorative Shades. Where more decorative effects are desired light white or opalescent glass is being used to good advantage. Much more attention is being paid to the design of the shades and to the quality of the glass used and the result of this study is the production of shades which, while they are ornamental, at the same time are also very efficient. Fig. 73 shows one of many lines of these shades and Fig. 74 is characteristic of the distribution curves obtained.

Reflectors for Indirect and Semi-Indirect Lighting. Reflectors for indirect lighting are often made a part of the construction of the building, as in "cove" lighting, but totally indirect lighting fixtures are available and Fig. 75 shows one such unit. Semi-indirect fixtures are, as a rule, rather less efficient than indirect as in the former case the bowls must be of opalescent glass and the absence of the reflector cuts down materially the amount of light reflected to the ceiling. Figs. 76 and 77 show an indirect fixture with a small diffusing globe at its base which illuminates the opalescent bowl below the reflector. This gives an efficient indirect illumination and at the same time provides the more artistic semi-indirect effect.

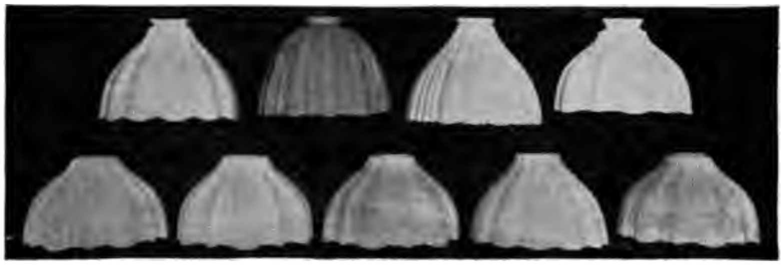


Fig. 73. Typical Decorative Shades for Incandescent Lighting

Incandescent Street Lighting. For incandescent street lighting where the system is ornamental and the lamps are mounted in clusters, opal enclosing globes are used; but in other installations a reflector, designed to give the best distribution of light for street illumination, is utilized. Fig. 78 shows a "radial wave" reflector and Fig. 79 illustrates the effect of this, and one other type of reflector, upon the distribution of light.

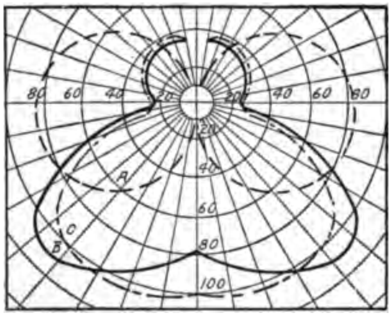


Fig. 74. Characteristic Distribution Curves for Reflectors Shown in Fig. 73.

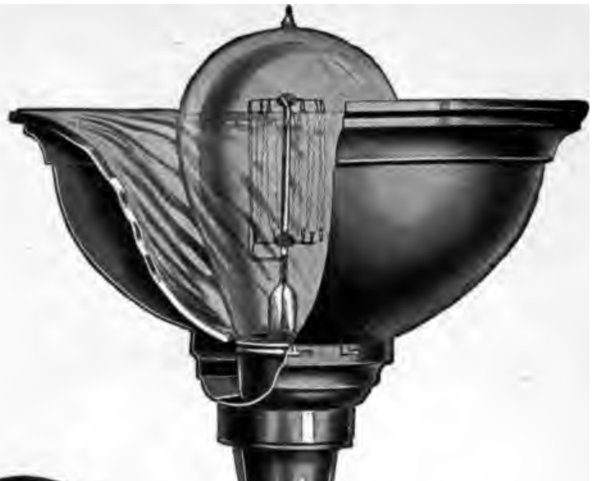


Fig. 75. Indirect Lighting Fixture with Part Cut Away to Show Position of Reflector
Courtesy of National X-Ray Reflector Company

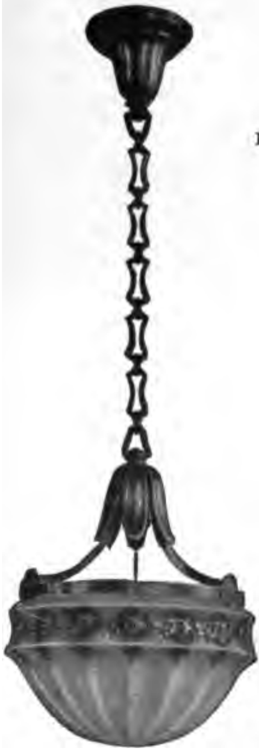


Fig. 76. Indirect Ceiling Fixture with Semi-Indirect Effect
Courtesy of National X-Ray Reflector Company

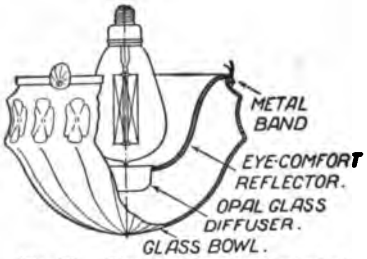


Fig. 77. Diagram Showing Method of Getting Semi-Indirect Effect by Use of Extra Diffusing Shade
Courtesy of National X-Ray Reflector Company

The possibilities in the way of shades and reflectors, both from the utilitarian and ornamental standpoint, are very great and a wide variety of models are now manufactured as standard.

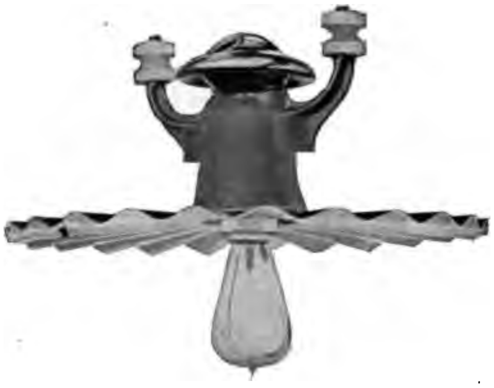


Fig. 78. Center Span Strain Insulator Suspension Fixture
Courtesy of General Electric Company

Special fixtures for the large lighting units, such as the various types of arc lights, are now available. Fig. 80 shows an enclosed arc lamp fitted with a shade and a concentric diffuser. The effect of this combination is best shown in Fig. 81. Fig. 82 shows the change in the illumination curve produced by such shading. Inverted arcs have some application where the light may be readily reflected and

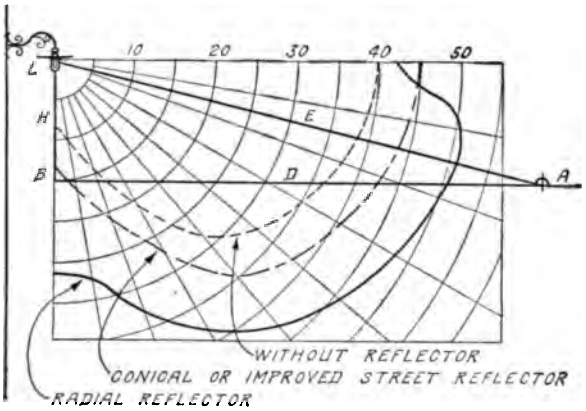


Fig. 79. Distribution Curves for Tungsten Lamp with Different Types of Reflectors

TABLE XXIII

Opal enclosing and clear outer	100 per cent
Clear enclosing and clear outer	91.2 per cent
Clear enclosing and opal outer	85.1 per cent
Opal enclosing and opal outer	82.7 per cent

diffused as in lighting large rooms with light finish. Reflectors of this general type are now being manufactured in such a form that they may be built in and become part of the ceiling of the room to be illuminated.

Opal Enclosing Globes. The use of opal enclosing globes is often recommended for arc lamps used for street lighting for the reason that they change the distribution of the light so that it covers a greater area and the light is so diffused as to obliterate shadows in the vicinity of the lamp. Table XXIII gives the efficiency of different globe combinations for street lighting, assuming the opal inner and the clear outer globes as 100 per cent.

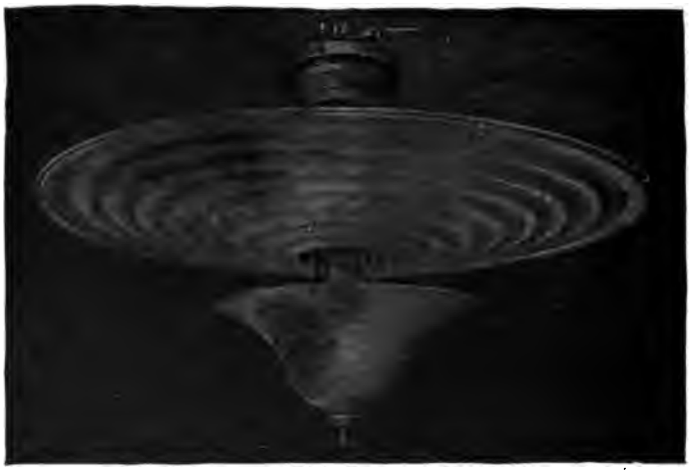


Fig. 80. Enclosed Arc Lamp Fitted with Shade and Concentric Diffuser

PHOTOMETRY

Photometry is the art of comparing the illuminating properties of light sources and forms one branch of scientific measurement. Its use in electric illumination is to determine the relative values of

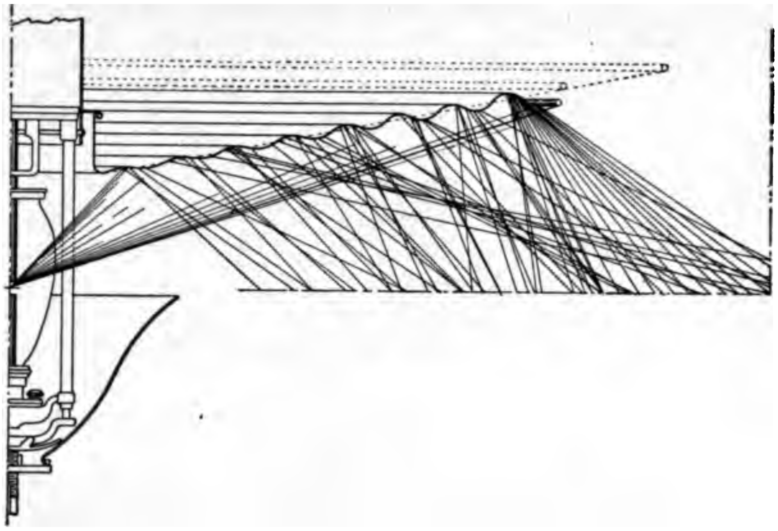


Fig. 81. Diagram Showing Effect of the Concentric Diffuser

different types of lamps as sources of illumination, together with their efficiency; also, by means of the principles of photometry, we are able to study the distribution of illumination for any given arrangement of light sources.

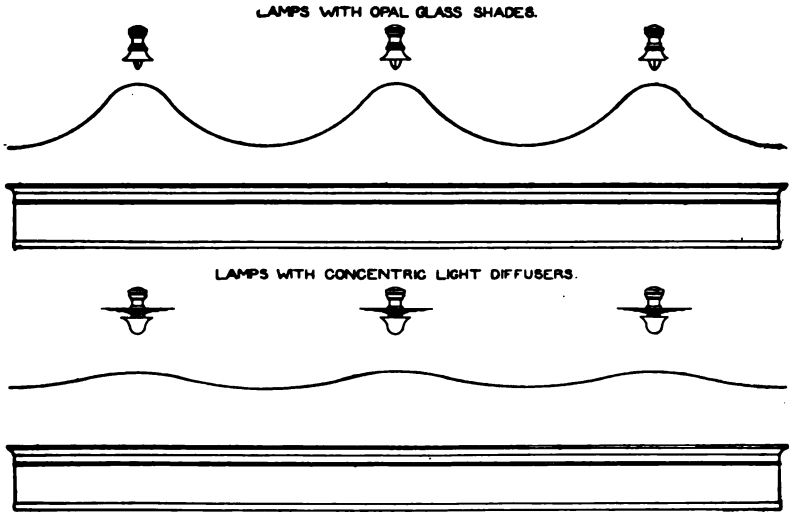

LAMPS WITH OPAL GLASS SHADES.
LAMPS WITH CONCENTRIC LIGHT DIFFUSERS.

Fig. 82. Illumination Curves for Lamps with and without Light Diffusers

LIGHT STANDARDS

Inasmuch as sources of light are compared with one another in photometry, we must have some standard, or unit, to which all light sources are reduced. This unit is usually the *candle-power* and the rating of most lamps is given in candle-power.

While the candle-power remains the unit and is based on the standard English candle, other light standards have been introduced and are much more desirable.

English Candle. The English candle is made of spermaceti extracted from crude sperm oil, with the addition of a small quantity of beeswax to reduce the brittleness. Its length is 10 inches, its diameter .9 inch at the bottom and .8 inch at the top, and its weight is one-sixth of a pound. Great care is taken in the preparation of the wick and the spermaceti. This candle burns with a normal height of flame of 45 millimeters and consumes 120 grams per hour when burning in dry air at normal atmospheric pressure. Under these conditions, the light given by a single candle is one candle-power.

When used for measurements, the candle should be allowed to burn at least 15 minutes before taking any readings. At the end of this period the wick should be trimmed, if necessary, and when the flame height reaches 45 millimeters, readings can be taken. The candle should not require trimming when the proper height of flame has been reached. It is best to weigh the amount of material consumed by balancing the candle on a properly arranged balance when the first reading is taken, and again balancing at the end of a suitable period—10 to 15 minutes. The candle-power of the unit is then, practically, directly proportional to the amount of the material consumed.

The objections to the candle as a unit are that it burns with an open flame which is subject to variation in height and to the effect of air currents. The color of the light is not satisfactory, being too rich in the red rays, and the composition of the spermaceti is more or less uncertain.

German Candle. The German candle is made of very pure paraffine, burns with a normal flame height of 50 millimeters, and is subject to the same disadvantages as the English candle. It may be necessary to trim the wick to keep the flame height at 50 millimeters. The light given is a trifle greater than for the spermaceti candle.

TABLE XXIV

Photometric Units

Bureau of Standards Unit, United States	1.000
Reichsanstalt Unit, Germany	0.998 × 0.88
National Physical Laboratory Unit, England	0.984
Laboratoire Central Unit, France	0.982

	CARCEL	HEFNER	VERNON-HARCOURT
Carcel	1.00	10.75	0.980
Hefner	0.0930	1.00	0.0915
Vernon-Harcourt (pentane)	1.020	10.95	1.0

The above values are at a barometric pressure of 760 mm. of mercury and a humidity for the Carcel and Vernon-Harcourt standards of 10.0 liters of water per cubic meter of dry air. The humidity for the Hefner unit is 8.8 liters of water to one cubic meter of dry air.

Carcel Lamp. The Carcel lamp is built according to very careful specifications and burns colza (rape seed) oil. It has been used to a large extent in France, but its present application is limited.

Pentane Lamp. This is a specially constructed lamp burning pentane, prepared by the distillation of gasoline between narrow limits of temperature. This standard, known also as the Vernon-Harcourt lamp, is not extensively used.

Amyl Acetate Lamp. This lamp, known also as the "Hefner lamp", is at present the most desirable standard. It is a lamp built to very careful specifications, especially with regard to the dimension of the wick tube. It burns pure amyl acetate and the flame height should be 40 millimeters. This flame height must be very carefully adjusted by means of gages furnished with the lamp. Amyl acetate is a colorless hydrocarbon prepared from the distillation of amyl alcohol obtained from fusel oil, with a mixture of acetic and sulphuric acids, or by distillation of a mixture of amyl acetate, sulphuric acid, and potassium acetate. It has a definite composition and must be pure for this use.

The most serious disadvantage of this standard is the color of the light, inasmuch as it has a decidedly red tinge and is not readily compared with whiter lights. Its value is affected somewhat by the moisture in the air and the atmospheric pressure but it excels all other standards in that it is quite readily reproduced.

Table XXIV gives the value of the candle-power units of different laboratories in terms of the unit of the Bureau of Standards and also the values of the units of the Carcel and Vernon-Harcourt in terms of the Hefner, as accepted by the International Photometric Commission.

Working Standards. *Incandescent Lamp.* The units just described, together with some others, form reference standards, but an incandescent lamp is generally used as the working standard in all photometers. An incandescent lamp, when used for this work, should be burned for about 200 hours, or until it has reached the point in the life curve where its value is constant, and it should then be checked by means of some standard when in a given position and at a fixed voltage. It then serves as an admirable working standard if the applied voltage is carefully regulated. Two such lamps should always be used—the one to serve as a check on the other; the checking lamp to be used for very short intervals only.

PHOTOMETERS

Basic Principle of Photometers. Two light sources are compared by means of a photometer which, in one of its simplest forms, consists of what is known as a "Bunsen screen" mounted on a carriage between the two lights being compared, with its plane at right angles to a line passing through the light sources, and arranged with mirrors or prisms so that both sides of the screen may be observed at once. The Bunsen screen consists of a disk of paper with a portion of either the center, or a section around the center, treated with paraffine so as to render it translucent. If the light falling on one side of this screen is in excess, the translucent spot will appear dark on that side of the screen and light on the opposite side. Care must be taken to see that the two sides of the screen are exactly alike, otherwise there will be an error introduced in using the screens. It is well to reverse the screen and check the readings whenever a new lot of lamps are to be tested. When the light falling on the two sides of the screen is the same, the transparent spot disappears. The values of the two light sources are then directly proportional to the square of their distances from the screen. As an example, consider a 16 candle-power lamp being compared with a standard candle on a photometer with a 300-centimeter bar. Say the translucent spot disappears when the screen is distant 60 centimeters from the standard candle, we then have the proportion

$$x : 1 = (240)^2 : (60)^2 = 16 : 1,$$

showing that the lamp gives 16 candle-power.

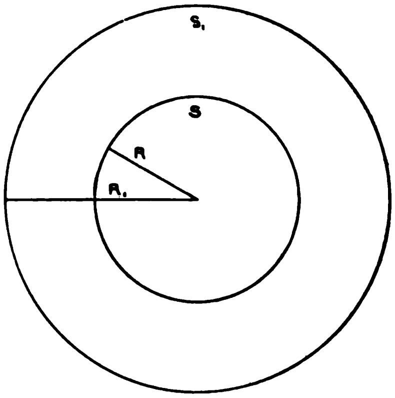


Fig. 83. Proof Diagram of the Law of Inverse Squares by Method of Concentric Spheres

The above law is known as the law of inverse squares and holds true only when the dimensions of the light sources are small compared with the distance between] them and when there are no reflecting surfaces present, as when the readings are taken in a dark room.

The proof that the light varies inversely with the square of the distance from the source is as follows:

Consider two spherical surfaces, Fig. 83, illuminated by a source of light at the center. The same quantity of light falls on both surfaces.

Area of $S = 4\pi R^2$ sq. ft. (R is in feet.)

Area of $S_1 = 4\pi R_1^2$ sq. ft.

Let Q equal total quantity of light and q and q_1 equal light falling on unit surface of the spheres S and S_1 respectively. Then

$$q = \frac{Q}{4\pi R^2}$$

$$q_1 = \frac{Q}{4\pi R_1^2}$$

$$q : q_1 = \frac{Q}{4\pi R^2} : \frac{Q}{4\pi R_1^2}$$

$$= 4\pi R_1^2 : 4\pi R^2$$

$$\frac{q}{q_1} = \frac{R_1^2}{R^2}$$

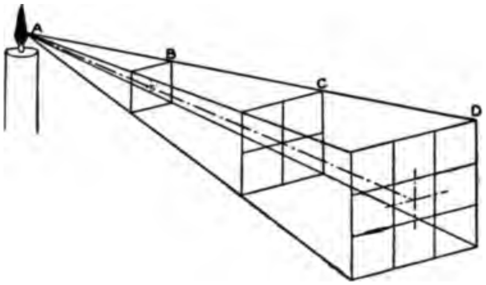


Fig. 84. Proof Diagram of the Law of Inverse Squares by Method of Screen Shadow

Fig. 84 shows the relation in another way. The area of C, distant two units from the source of light A, is four times that of B, which is distant one unit.

Lummer-Brodhun Photometer. In addition to the Bunsen screen described, there are several other forms of photometers, the most important of which is the Lummer-Brodhun. The essential feature of this instrument is the optical train which serves to bring into contrast the portions of the screen illuminated by the two sources of light. Referring to Fig. 85 the screen *S* is an opaque screen which reflects the light falling upon it from *L*, to the mirror *M*, when it is again reflected to the pair of glass prisms *A*, *B*. The surfaces are ground to fit perfectly at *s r* and any light falling on this surface will pass through the prisms. Light falling on the surface *a r* or *b s* will be reflected as shown by the arrows. We see then that the light from *L*, which falls on *a r* and *b s*, is reflected to the eyepiece or telescope *T*, while that falling on *s r* is transmitted to and absorbed by the black interior of the containing box. Likewise, the light from the screen L_1 is reflected by the screen M_1 to the pair of prisms *A*, *B*. The rays falling on the surface *s r* pass through to the telescope *T*, while the rays falling on *a r* and *b s* are reflected and absorbed by the black lining of the case. The field of light, as then viewed through the telescope, appears as a disk of light produced by the screen L_1, surrounded by an annular ring of light produced by *L*. When the illumination on the two sides of the screen

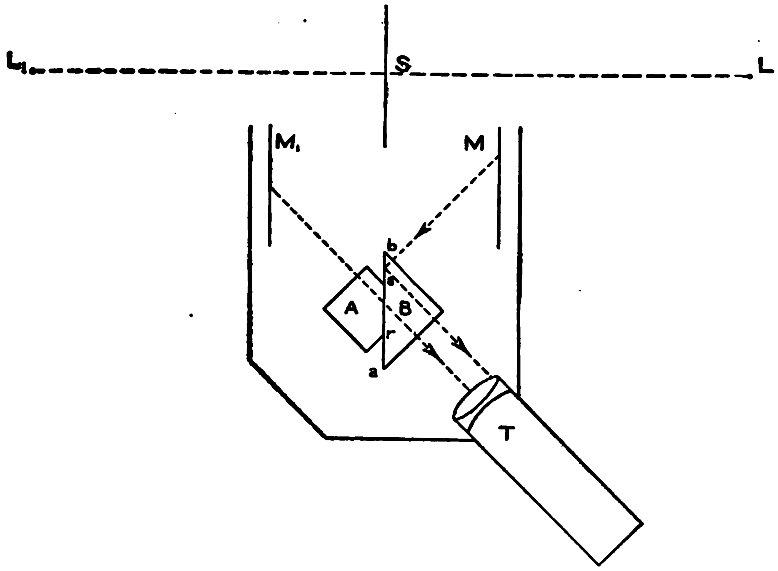


Fig. 85. Diagram of Lummer-Brodhun Screen

is the same, the disk and ring appear alike and the dividing circle disappears.

In using this screen, it is mounted the same as the Bunsen screen and readings are taken in the same manner. The screen and prisms are arranged so that they can be reversed readily and two readings should always be taken to compensate for any inequalities in the sides of the screen and the reflecting surfaces, a mean of the two readings

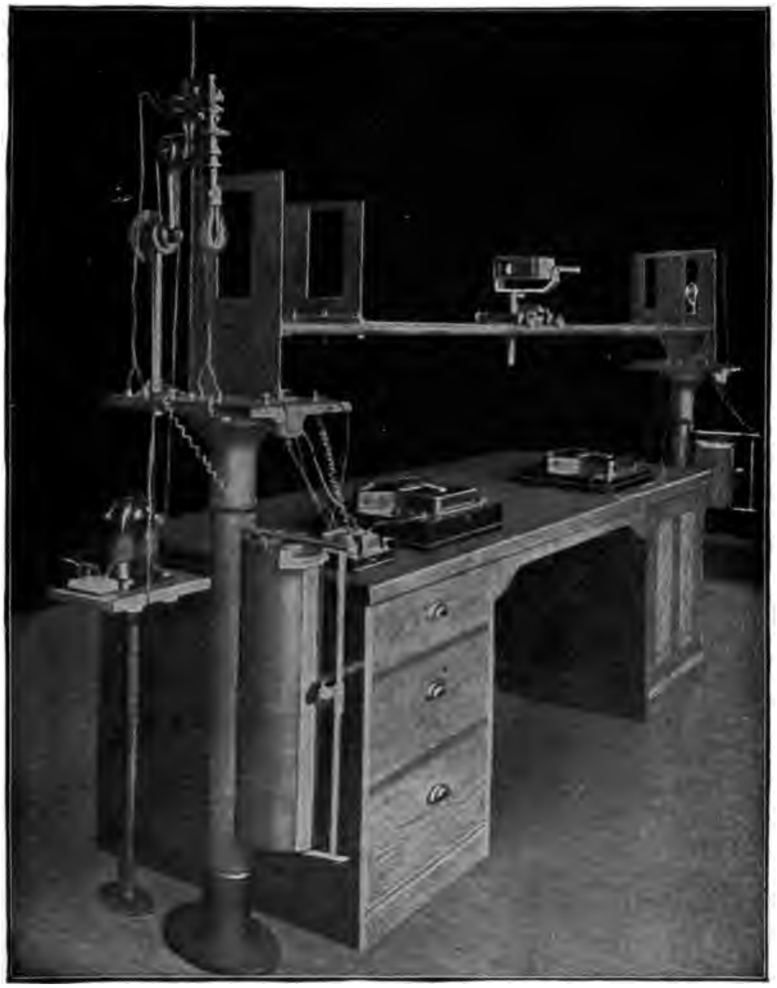


Fig. 86. Complete Photometer with Lummer-Brodhun Screen

serving as the true reading. This form of screen is used when especially accurate comparisons are required.

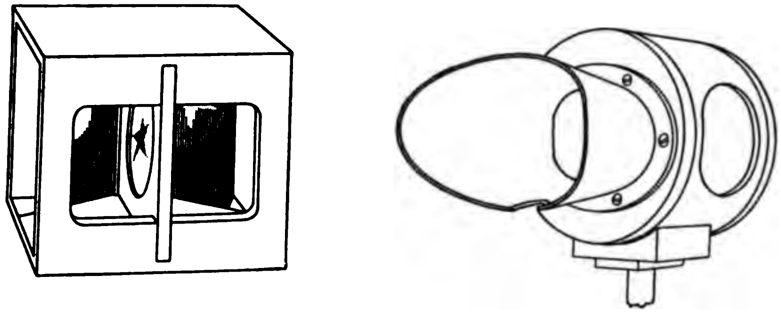


Fig. 87. Bunsen Screen and Sight Box

Fig. 86 shows a complete photometer with a Lummer-Brodhun screen, while Fig. 87 shows a Bunsen screen and sight box. In Fig. 86, the lamps are shaded by means of curtains so as to leave only a small opening toward the screen. If the lights are properly screened, photometric measurements may be made in rooms having light-colored walls.

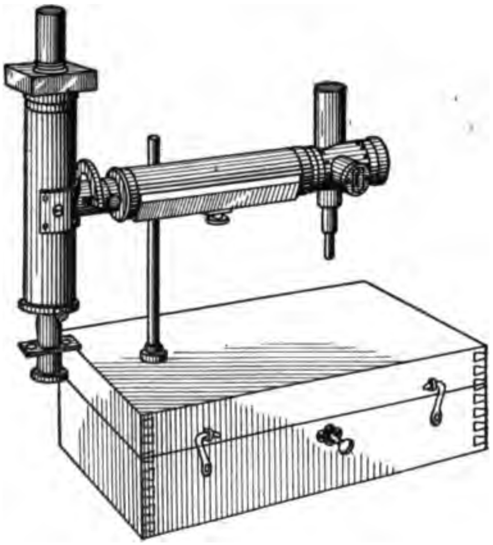
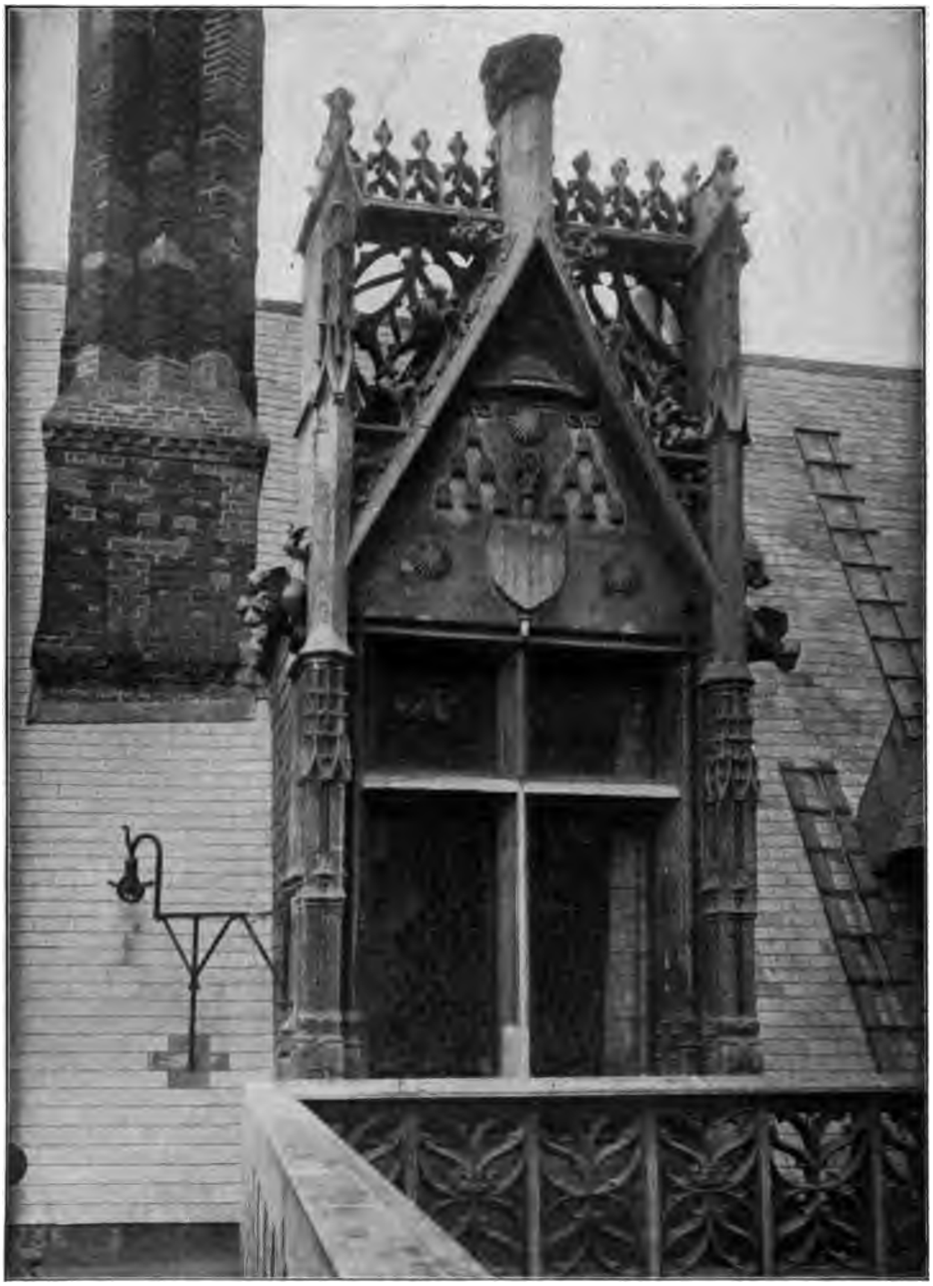


Fig. 88. Weber Portable Photometer



DORMER ON MUSÉE DE CLUNY, PARIS, FRANCE
Built in the Fifteenth Century   Note the Figure Sculpture at Sides of Dormer.

Weber Photometer. As an example of a good portable type, the Weber photometer is shown in Fig. 88. This photometer is very compact and is especially adapted to measuring intensity of illumination as well as the value of light sources; it may be used for exploring the illumination of rooms or the lighting of streets.

This apparatus consists of a tube *A*, Fig. 89, which is mounted horizontally and contains a circular opal glass plate *f*, which is movable by means of a rack and pinion. To this screen is attached an index finger which moves over a scale attached to the outside of the tube. A lamp *L*, burning benzine, is mounted at the end of this tube. The benzine used should be as pure as possible and the flame height should be carefully adjusted to 20 mm. when taking readings. At right angles to the tube *A* is mounted the tube *B* which contains an eyepiece at *O*, a Lummer-Brodhun contrast prism at *p*, and a support for opal or colored glass plates at *g*.

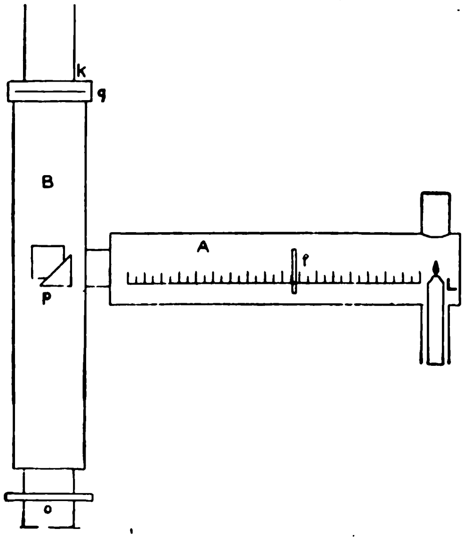


Fig. 89. Diagram of Weber Photometer

Operation. The tube *B* is turned toward the source of light to be measured, the distance from the light to the screen at *g* being noted. The light from this source is diffused by the screen at *g*, while that from the standard is diffused by the screen *f*. By moving the screen *f*, the light falling on either side of the prism *p* can be equalized. The value of the unknown source can be determined from the reading of the screen *f*, the photometer having previously been calibrated by means of a standard lamp in place of the one to be measured. The calibration may be plotted in the form of a curve or it may be denoted by a constant C, when we have the formula

$$I' = C\frac{L^2}{l^2}$$

C corresponds to a particular plate at g; l is distance of screen f from the benzine lamp; and L is distance from the screen g to the light source being measured. Screens of different densities may be used at g depending on the strength of the light source.

When used for measuring illumination, a white screen is used in connection with this photometer. The screen is mounted in front of the opening at g, and turned so that it is illuminated by the source being considered. Readings of the screen f are taken as before. A calibration curve is plotted for the instrument, using a known light source at a known distance from the white screen when the instrument is mounted in a dark room.

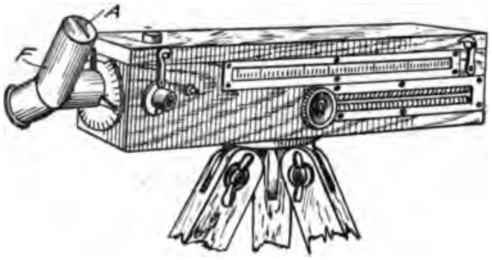


Fig. 90. Sharp-Millar Photometer

Portable Photometers. There is a large variety of portable photometers available which give more or less satisfactory results. An instrument especially designed with a view to portability and to overcoming some of the defects of other instruments on the market is the "Universal photometer," more commonly known as the "Sharp-Millar photometer" from the names of its inventors. Views of this instrument are shown in Figs. 90 and 91. It is adapted to the measurement of the intensity of light sources as well as to the illumination at any point, as is the Weber photometer. The photometer screen or photometric device is shown at *B*, and consists of a special form of Lummer-Brodhun optical screen. A standardized incandescent lamp *C* is used as the photometric standard and this may be connected to a battery, or be adapted to use on the mains supplying the lamps in the room where measurements are to be taken. All stray light is carefully screened from the interior of the box by a series of screens *G*. The instrument scale is calibrated in foot candles and in candle-powers.

When illumination is to be measured, a specially selected translucent screen is placed at *A* and the illumination of this plate, which is placed at the point and in the plane where the value of the illumination is desired, is reflected to the photometric device by the mirror at *H*. A second plate *K* is mounted so as to be illuminated by the standard lamp and the photometer is balanced by making the illumination of *A* and *K* the same. When the intensity of a light source is to be determined, the screen at *A* is replaced by a small aperture and a diffusing surface *I* is put in place of the mirror *H*. The illumination of *I* is now compared with the illumination of *K*, and when the two are made equal, the photometer reads the candle-power of the light source, or some multiple of this candle-power. The range of this instrument is increased by the use of suitably arranged absorbing screens which may be readily inserted or removed and, as ordinarily equipped, the range in foot-candles is approximately from .004 to

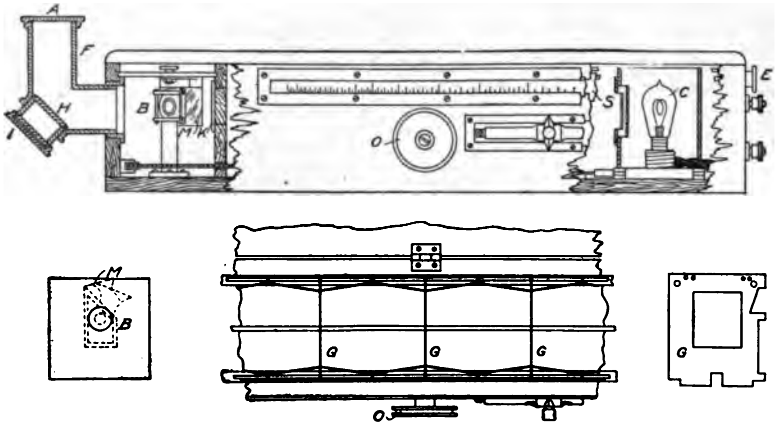


Fig. 91. Sectional View of Sharp-Millar Photometer

2000. The variety of uses which can be made of such a photometer is large, and some idea of its portability can be obtained from the dimensions of the box, 24″×4½″×5″, and its weight, fully equipped, of 8 pounds. Considering its compactness, this photometer is capable of great accuracy.

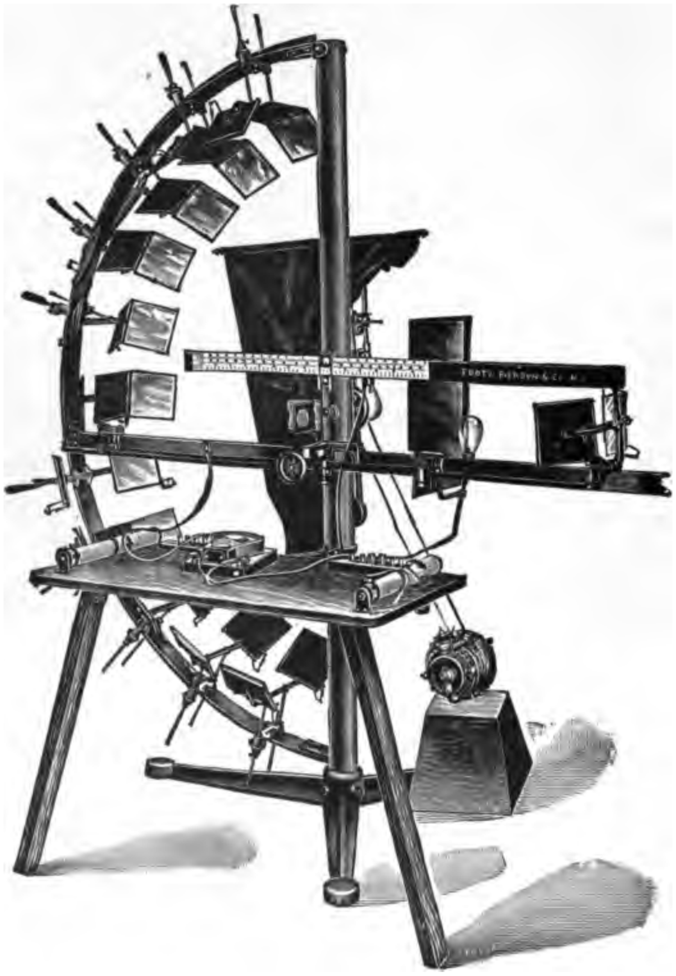


Fig. 92. Matthews Integrating Photometer

Integrating Photometers. *Matthews.* This photometer is used to some extent and a very good idea of its construction can be obtained from Fig. 92. By means of a system of mirrors, the light given by the lamp in several directions may be integrated and thrown on the photometer screen for comparison with the standard, the result giving the mean spherical candle-power from one reading. By covering all but one pair of screens, the light given in any one direction is easily determined.

Another type of integrating photometer is known as the "integrating sphere" or globe photometer. If a light source is placed within a sphere the interior walls of which are coated with a white diffusing surface the illumination of that surface at any point is due partly to the light falling on it directly, and partly to the light reflected from the remainder of the surface of the sphere. The reflected light is proportional to the total flux of light from the light source and so, if the direct light is screened from the point considered, its illumination is proportional to the total flux of light, and hence to the mean spherical candle-power of the light source.

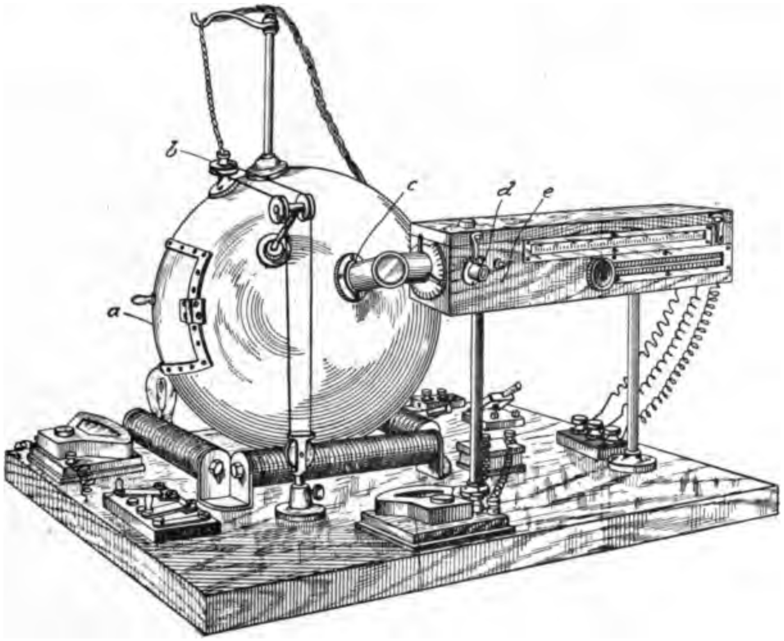


Fig. 93. Eighteen-Inch Integrating Sphere Equipped with Photometer

The practical application of this principle is so to arrange our properly coated sphere that the lamp to be tested may be readily inserted; to replace a small portion of the sphere by a piece of unpolished white glass; to shut off the direct rays of the lamp to be measured from this glass surface; and so to mount a photometer screen and standard lamp that the illumination of the glass section can be measured. Under these conditions the illumination of the glass screen is proportional to the mean spherical candle-power of the lamp under test. A substitution method is used in practice. A standardized lamp of the general type of the one to be tested is mounted in the sphere and the constant of the instrument for this type of lamp is determined. The unknown lamps are then put in place and their candle-power is readily determined, once the constant of the instrument is known. Figs. 93 and 94 give some views of the integrating sphere and indicate the range of the sizes in which it may be constructed.

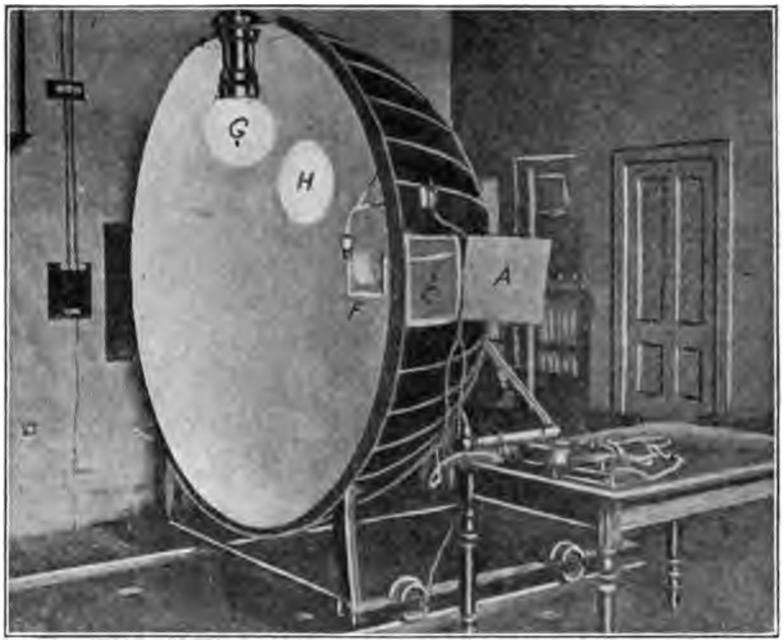


Fig. 94. Interior of 80-Inch Integrating Sphere

INCANDESCENT LAMP PHOTOMETRY

Apparatus. Some sort of screen, either the Bunsen type or the Lummer-Brodhun screen preferred, should be mounted on a carriage moving on a suitable scale, and the lamp holders, one for the standard, the other for the lamp to be tested, are mounted at the ends of this scale. There are several types of so-called station photometers arranged so as to be very convenient for testing incandescent lamps. Fig. 95 shows one form of station photometer manufactured by Queen and Company. The controlling rheostats and shielding curtains are not shown here. Fig. 96 shows a form of portable photometer for incandescent lamps. The length of scale should not be less than 100 centimeters, and 150 to 200 centimeters is preferred. This s e may be divided into centimeters or, for the purpose of doing ray with much of the calculation, the scale may be a *proporti*
This scale is based on the law of inverse squares and r

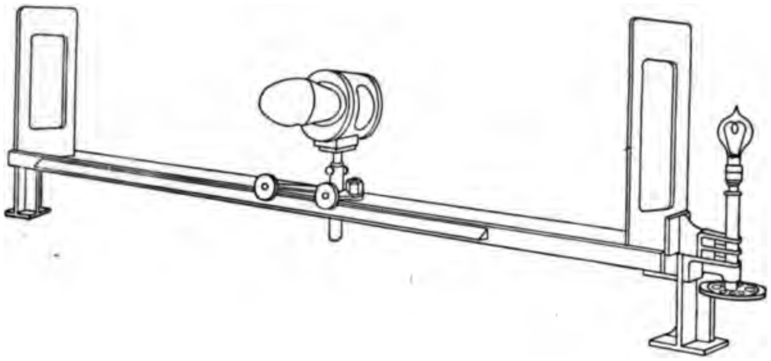


Fig. 95. Station Photometer

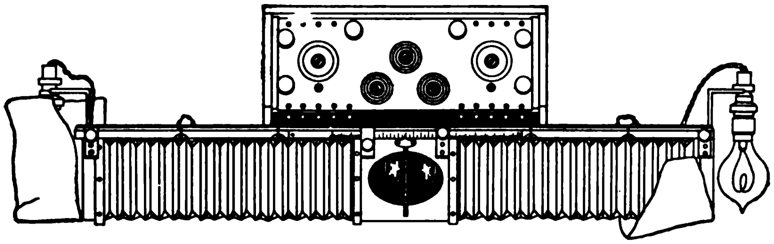


Fig. 96. Portable Photometer for Incandescent Lamps

ratio of the squares of the distances from the two lights being compared. If the standard used always has the same value, the scale may be made to read in candle-powers directly.

For mean horizontal candle-power measurements, the lamp should be rotated at 180 revolutions per minute, when mounted in a vertical position. Lamps giving a uniform horizontal distribution curve need not be rotated.

For distribution curves a universal lamp holder, which will allow the lamp to be placed in any position and which indicates this position, is used.

For mean spherical candle-power the following method is used when the Matthews or integrating-sphere photometer is not available:

Measurement of the Spherical Intensity. For convenience, the tip of the lamp and its base may be termed the north and south poles, respectively. The lamp is placed in an adjustable holder and readings taken with the lamp in thirty-eight positions, as follows:

The mean of 13 readings taken at intervals of 30° is taken to give the mean horizontal candle-power.

Beginning again at 0° azimuth, thirteen readings are made in the prime meridian or vertical circle, the interval again being 30° and the last reading checking the first.

It will be noticed that four readings, two being check readings, have been made at 0° azimuth in each case. The mean of the four is taken as the *standard reading*, it being the value of the intensity, in this position, should the lamp be used as a standard.

Additional sets of thirteen readings each—the last reading checking the first one—are similarly made on each of the vertical circles through 45°, 90°, and 135° azimuth.

In combining the readings for the mean spherical intensity, a note is taken of the repetitions.

Neglecting the repetitions, which may also be omitted in part in the practice of the method, there remain thirty-eight points, as follows:

	DISTRIBUTED VALUES
The mean of four measurements at the north pole of the lamp	1
Four measurements on each of the vertical circles through 0° and 90° azimuth at vertical circle readings of 60°, 120°, 240°, and 300°	8
Four measurements on each of the vertical circles through 0°, 45°, 90°, and 135° azimuth at vertical circle readings of 30°, 150°, 210°, and 330°	16
Twelve measurements 30° apart at the equator	12
Four null values at the south pole of the lamp	1
Total number of effective measurements	38

The points thus laid off on the reference sphere are approximately equidistant, being somewhat closer together at the equator than at the poles.

When the lamp is rotated, readings are taken for each 15° or 30° in inclination, from 0° to 90° and from 0° to 270°. These are integrated values for their corresponding parallels of latitude on the unit sphere.

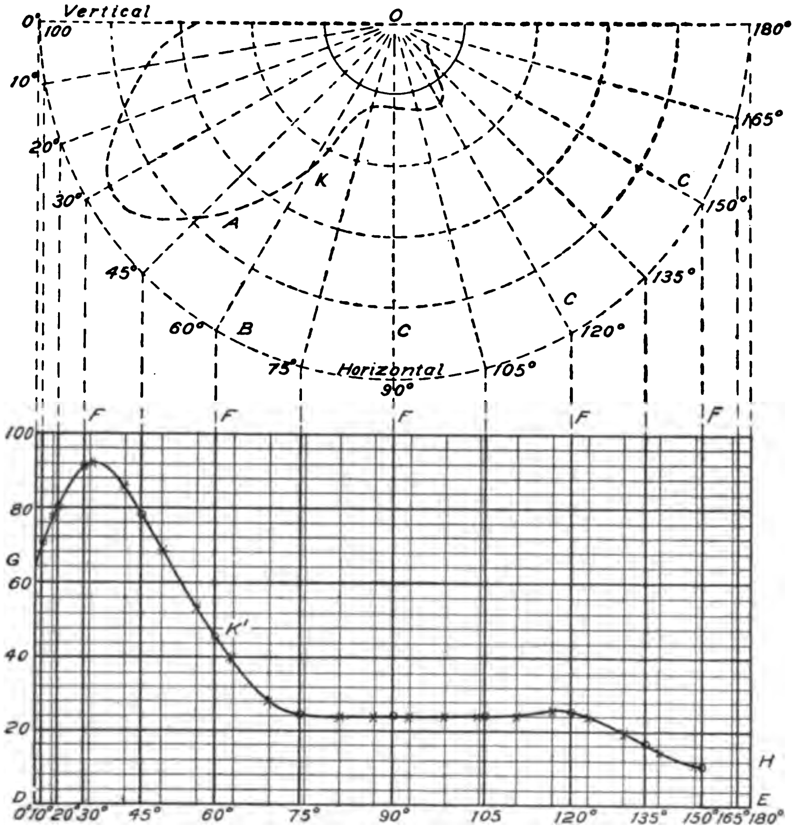


Fig. 97. Rousseau Diagram for Gem Lamp with Bowl Reflector

The mean spherical candle-power from these readings may best be obtained by plotting a distribution curve from the readings, determining the area of this closed curve by means of a planimeter and taking the radius of an equivalent circle as the value for the mean spherical candle-power.

Rousseau Diagram. The Rousseau diagram may be used for determining the mean spherical candle-power of a lamp when its vertical distribution curve is known. Fig. 97 shows such a diagram made up for a gem lamp with a bowl reflector. Where the horizontal distribution curve of the lamp is not uniform, the values for the vertical distribution curve should be taken with the lamp rotating so as to give average values at each angle. One-half of the distribution curve is drawn to scale *A* and a circle *B* is drawn with the source of light *O* as a center. Radii *C* are drawn at equal angles about the light source and extended until they intersect the circle *B*. The points of intersection of these lines with the circle are projected upon the straight line *D E*. Distances from this line are laid off on the verticals *F* equal to the distances from the center of the circle to the points where the corresponding radii cut the distribution curve. The area enclosed between the straight line *D E* and a curve drawn through the points just determined, *G H*, divided by the base line, is equal to the mean spherical candle-power of the lamp. If the mean candle-power of the lamp within a certain angle is desired, it is only necessary to find the area of the diagram within the space indicated by that angle and divide by the corresponding base.

In all tests the voltage of the lamp must be very closely regulated. A storage battery forms the ideal source of current for such purposes. In testing incandescent lamps, a standard similar to the lamp being tested is desirable and it should, preferably, be connected to the same leads. Any variation in the voltage of the mains then affects both lamps and the error introduced is slight.

ARC LIGHT PHOTOMETRY

Method Used. Owing to the variation of the amount of light given out by an arc lamp in one direction at any time, due to variation of the qualities of the carbons, position of the arc, and also on account of the color of the light, etc., the photometry of arc lamps is much more difficult than that of incandescent lamps. The curves shown in Figs. 26 and 27 are average distribution curves taken from several lamps and will vary considerably for any one lamp. If the arc is enclosed, this variation is not so great.

The working standard should be an incandescent lamp run at a voltage above the normal so that the quality of the light will compare favorably with that of the arc. Since an incandescent lamp deteriorates rapidly when run at over voltage, the standard can be used only for short intervals and must be frequently checked.

Since an arc lamp can be mounted in one position only, mirrors must be used to obtain distribution curves. A mirror is used mounted at 45° with the axis of the photometer and arranged so as to reflect the arc when in different positions. A mirror absorbs a certain per cent of the light falling upon it and this percentage must be determined by using lamps previously standardized. The length of the photometer bar must include the distance from the mirror to the arc.

The Weber photometer is well adapted to arc-light measurements inasmuch as appropriate screens may be used to cut down the intensity of the light.

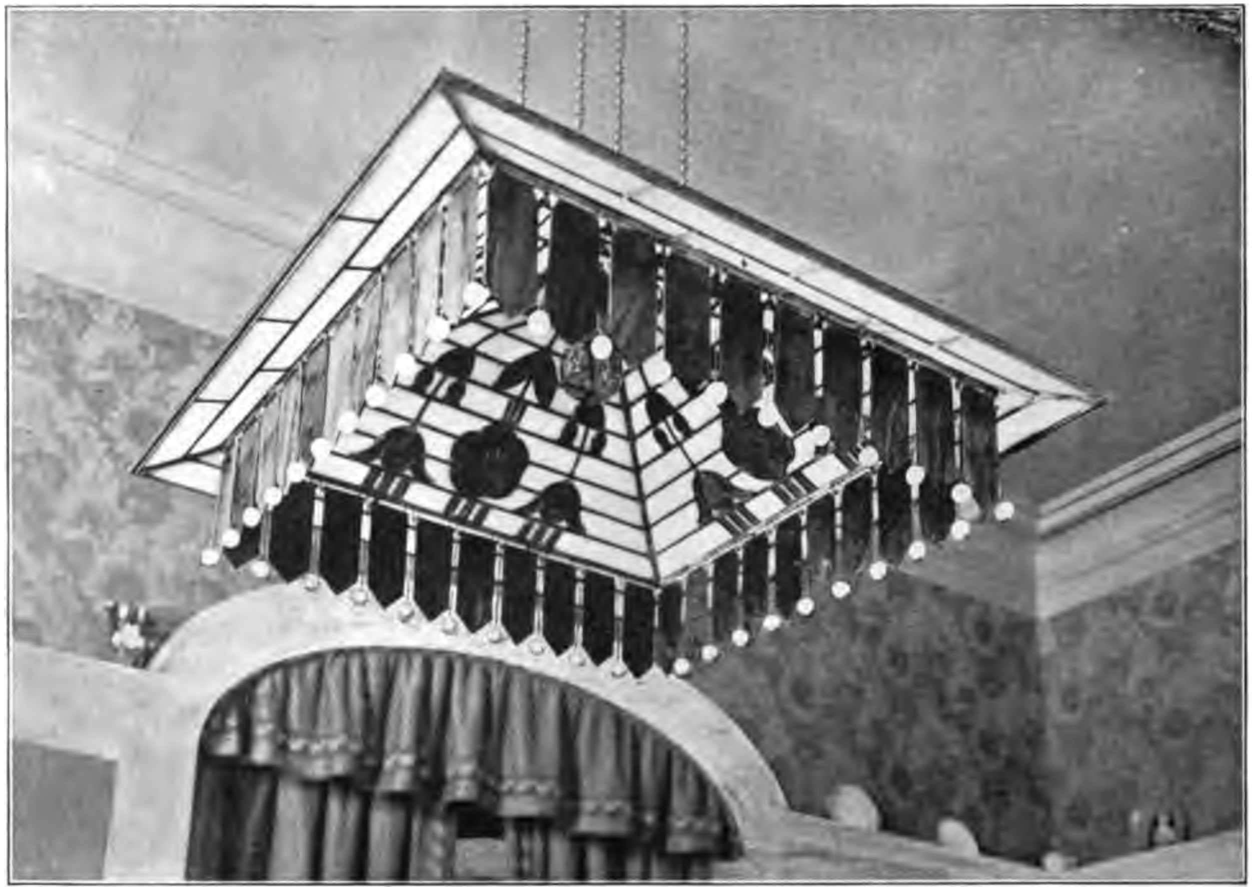
A special form of the Matthews photometer is also used for testing arc lamps.

Illuminometer. For the comparison of the illumination from arc lamps as installed in service, an instrument known as an "illuminometer" is sometimes used. This consists of a light wooden box, readily portable, having a black interior and arranged with two openings. One of these openings is for the purpose of admitting light, from the source being considered, to a printed card. The other opening is for the purpose of viewing this card, when illuminated by the light source. The printing on the card is made up from type of different sizes and the smallest size which is legible, together with the distance from the light source, is noted. Another method of application is to select some definite size of type and then to move the instrument from the light source to a point where this type is just legible and note the distance. From similar measurements taken on different lamps a good comparison may be obtained. Such an instrument is very convenient to use and results, obtained by different observers, check very closely.

Flicker Photometer. The flicker photometer is used for the comparison of different colored lights, the basis for comparison being that each light, though different in color, shall produce light sensations equally intense for the purpose of distinguishing outlines. It consists, in one form, of an arrangement by means of which a sectored disk is rotated in front of each light source, these disks being so arranged that the light from one source is cut off while the other falls on the screen and, *vice versa*, any form of screen being used for making the comparison. The disks must be revolved at such a rate that the light, viewed from the opposite side will appear continuous. When the illumination of the two sides of the screen, under these conditions, is not the same, there will be a perceptible flicker and the screen should be so adjusted that this flicker disappears. The value of the light source can then be calculated from the screen reading in the usual manner. Another device consists of the use of a special lens mounted in front of a wedge-shaped screen, the lens being constructed so as to reverse the image of the two sides of the screen, as viewed by the eye, when such lens is in front of the screen. The lens is so mounted that it can be oscillated rapidly in front of the screen, giving the same result as would be obtained were it possible to reverse the screen at such a rapid rate as to cause the illumination on the two sides to appear continuous. The setting of this screen is accomplished as with the more simple forms.

Still another flicker photometer, the Simmance-Abady, makes use of a rotating wheel. This wheel is made of a white material having a diffusing surface and its edge is so beveled that during part of a revolution a surface illuminated by one of the light sources is viewed through the eyepiece of the instrument and, during the other part of the revolution, a surface viewed by the second light source is observed. The flicker occasioned by this change disappears when the screen is brought to a point where it is equally illuminated by the two light sources.

By the use of such forms of photometers, it is found that results with different colored lights can be obtained which are comparable with results obtained with lights of the same color.



DETAIL OF DINING-ROOM TABLE LANTERN IN HOUSE AT WAUKEGAN, ILL.

R. C. Spencer, Jr., Architect, Chicago, Ill.

SHEET METAL WORK

PART I.

SKYLIGHT WORK

Where formerly skylights were constructed from wrought iron or wood, to-day in all the large cities they are being made of galvanized sheet iron and copper. Sheet metal skylights, having by their peculiar construction lightness and strength, are superior to iron and wooden lights; superior to iron lights, inasmuch as there is hardly any expansion or contraction of the metal to cause leaks or breakage of glass; and superior to wooden lights, because they are fire, water and condensation-proof, and being less clumsy, admit more light.

The small body of metal used in the construction of the bar and curb and the provisions which can be made to carry off the inside condensation, make sheet metal skylights superior to all others constructed from different material.

CONSTRUCTION

The construction of a sheet metal skylight is a very simple matter, if the patterns for the various intersections are properly developed. For example, the bar shown in Fig. 145 consists of a piece of sheet metal having the required stretchout and length, and bent by special machinery, or on the regular cornice brake, into the shape shown, which represents strength and rigidity with the least amount of weight. A A represent the condensation gutters to receive the condensation from the inside when the warm air strikes against the cold surface of the glass, while B B show the rabbets or glass-rest for the glass.

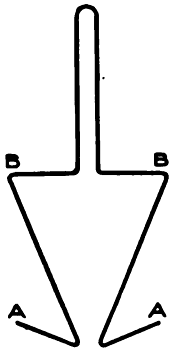


Fig. 145.

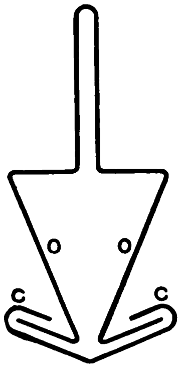


Fig. 146.

In Fig. 146, C C is a re-enforcing strip, which is used to hold the two walls O O together and impart to it great rigidity. When skylight bars are required to bridge long spans, an internal core is made of sheet metal and placed as shown at A in Fig. 147, which adds to its weight-sustaining power. In this figure B B shows the glass laid on a bed of putty with the metal cap C C C, resting snugly against the glass, fastened in position by the rivet or bolt D D. Where a very large span is to be bridged a bar similar to that shown in Fig. 148 is used. A heavy core plate A made of $\frac{1}{4}$-inch thick metal is used, riveted or bolted to the bar at B and B. In construction, all the various bars terminate at the curb shown at A B C in Fig. 149, which is fastened to the wooden frame D E.

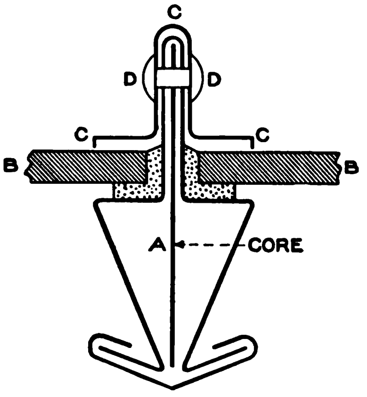


Fig. 147.

The condensation gutters C C in the bar *b*, carry the water into the internal gutter in the curb at *a*, thence to the outside through holes provided for this purpose at F F. In Fig. 150 is shown a sectional view of the construction of a double-pitched skylight. A shows the ridge bar with a core in the center and cap attached over the glass. B shows the cross bar or clip which is used in large skylights where it is impossible to get the glass in one length, and where the glass must be protected and leakage prevented by means of the cross bar, the gutter of which conducts the water into the gutter of the main bar, thence outside the curb as before explained. C is the frame generally made of wood or angle iron and covered by the metal roofer with flashing as shown at F. D shows the skylight bar with core showing the glass and cap in position. E is the metal curb against which the bars terminate, the condensation being let out through the holes shown.

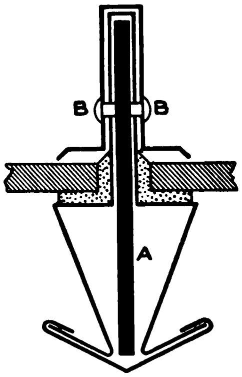
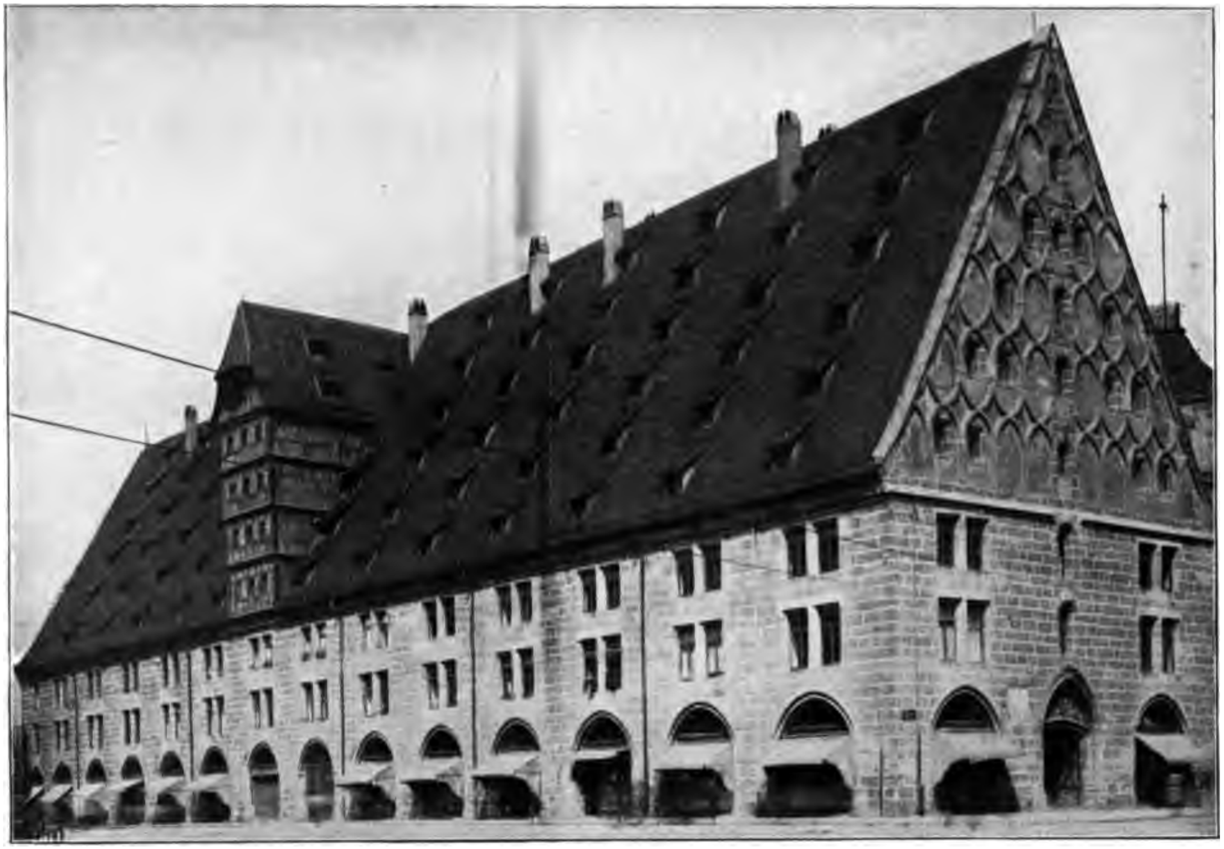


Fig. 148.

In constructing pitched skylights having double pitch, or being hipped, the pitch is usually one-third. In other words it is one-third



MAUTH GEBAUDE, NÜRNBERG, GERMANY
Hans Beheim, Architect.
Built in 1498-1502. The Steep Tile Roof is an Imposing Feature. Note the Decorative Treatment of the Gable End.

of the span. If a skylight were 12 feet wide and one-third pitch were required, the rise in the center would be one-third of 12, or 4 feet. When a flat skylight is made the pitch is usually built in the wood or iron frame and a flat skylight laid over it. The glass used in the construction of metallic skylights is usually $\frac{1}{4}$-inch rough or ribbed glass; but in some cases heavier glass is used.

If for any reason it is desired to know the weight of the various thickness of glass, the following table will prove valuable.

Weight of Rough Glass Per Square Foot.

Thickness in inches.	$\frac{1}{8}$.	$\frac{3}{16}$.	$\frac{1}{4}$.	$\frac{3}{8}$.	$\frac{1}{2}$.	$\frac{5}{8}$.	$\frac{3}{4}$.	1.
Weight in pounds.	2.	$2\frac{1}{2}$.	$3\frac{1}{2}$.	5.	7.	$8\frac{1}{2}$.	10.	$12\frac{1}{2}$.

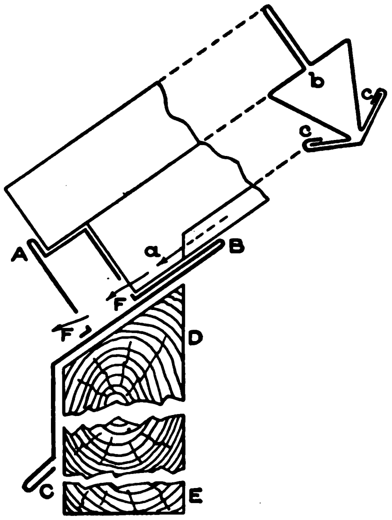


Fig. 149.

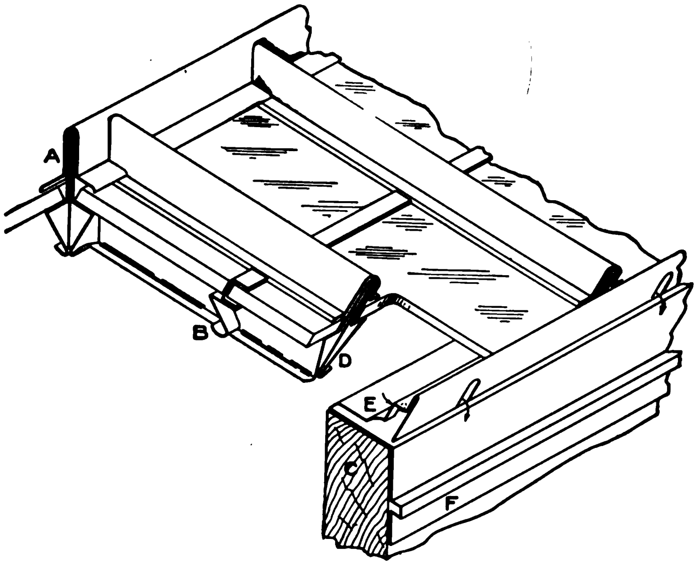


Fig. 150.

SHOP TOOLS

In the smaller shops the bars are cut with the hand shears and formed up on the ordinary cornice brake. In the larger shops, the strips required for the bars or curbs are cut on the large squaring shears, and the miters on the ends of these strips are cut on what is known as a miter cutter. This machine consists of eight foot presses on a single table, each press having a different set of dies for the purpose of cutting the various miters on the various bars. The bars are then formed on what is known as a Drop Press in which the bar can be formed in two operations to the length of 10 feet.

METHOD EMPLOYED IN OBTAINING THE PATTERNS

The method to be employed in developing the patterns for the various skylights is by parallel lines. If, however, a dome, conservatory or circular skylight is required, the blanks for the various curbs, bars, and ventilators, are laid out by the rule given in Sheet Metal Work, Part IV, under "Circular Work".

VARIOUS SHAPES OF BARS

In addition to the shapes of bars shown in Figs. 145 to 148 inclusive, there is shown in Fig. 151 a plain bar without any condensation gutters, the joint being at A. B B represents the glass resting on the rabbets of the bar, while C shows another form of cap which covers the joint between the bar and glass. Fig. 152 gives another form of bar in which the condensation gutters and bar are formed from one piece of metal with a locked hidden seam at A. Fig. 153 shows a bar on which no putty is required when glazing. It will be noticed that it is bent from one piece of metal with the seam at A, the glass B B resting on the combination rabbets and gutters C C. D is the cap which is fastened by means of the cleat E. These cleats are cut about ½-inch wide from soft 14-oz. copper, and riveted to the top of the bar

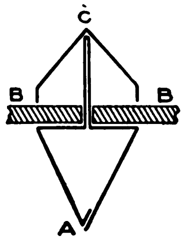


Fig. 151.

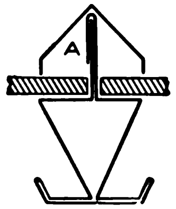


Fig. 152.

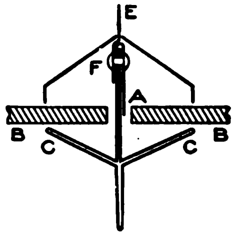


Fig. 153.

at F; then a slot is cut into the cap D as shown from *a* to *b* in Fig. 154; then the cap is pressed firmly onto the glass and the cleat E turned down which holds the cap in position.

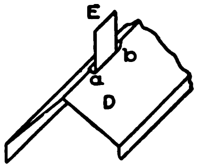


Fig. 154.

When a skylight is constructed in which raising sashes are required, as shown in Fig. 155, half bars are required at the sides A and B, while the bars on each side of the sash to be raised are so constructed that a water-tight joint is obtained when closed. This is shown in Fig. 156, which is an enlarged section through A B in Fig. 155. Thus in Fig. 156, A A represents the two half bars with condensation gutters as shown, the locked seam taking place at B B. C C represent the two half bars for the raising sash with the caps D D attached to same, as shown, so that when the sash C C is closed, the caps D D cover the joint between the glass E E and the stationary half bars. F F are the half caps soldered at *a a* to the bars C C which protect the joints between the glass H H and the bars C C.

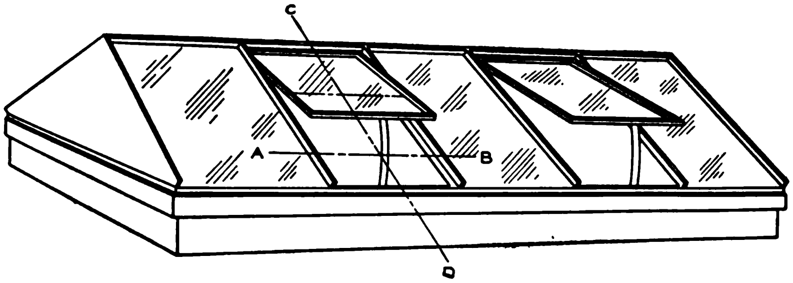


Fig. 155.

VARIOUS SHAPES OF CURBS

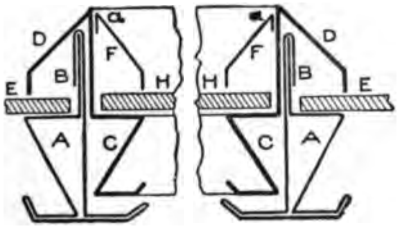


Fig. 156.

In Figs. 157, 158 and 159 are shown a few shapes of curbs which are used in connection with flat skylights. A in Fig. 157 shows the curb for the three sides of a flat skylight, formed in one piece with a joint at B, while C shows the cap, fastened as previously described. "A" shows the height at the lower end of the curb, which is made as high as the glass is thick and allows the water to run over. In Fig. 158, A is another form of skylight formed in one piece and riveted at B; *a* shows the height at the lower end. In the previous figures the frame on which the metal curb rests is of wood, while in Fig. 159 the frame is

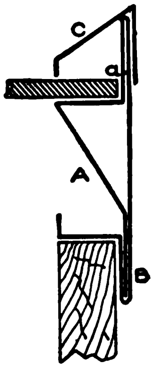


Fig. 157.

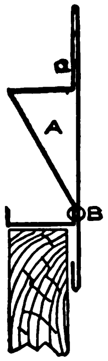


Fig. 158.

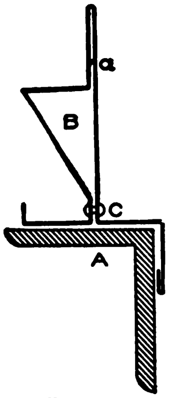


Fig. 159.

of angle iron shown at A. In this case the curb is slightly changed as shown at B; bent in one piece, and riveted at C. In Figs. 160, 161, and 162 are shown various shapes of curbs for pitched skylights in addition to that shown in Fig. 149. A in Fig. 160 shows a curb formed in one piece from *a* to *b* with a condensation hole or tube shown at B.

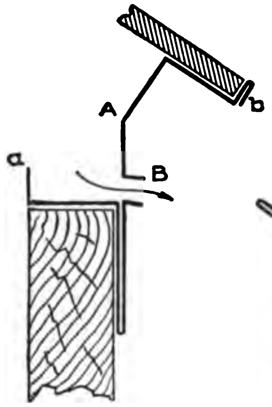


Fig. 160.

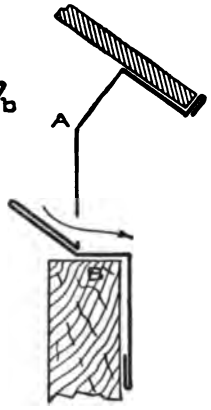


Fig. 161.

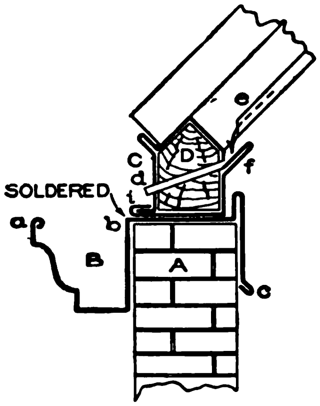


Fig. 162.

In Fig. 161 is shown a slightly modified shape A, with an offset to rest on the curb at B. When a skylight is to be placed over an opening whose walls are brick, a gutter is usually placed around the wall, as shown in Fig. 162, in which A represents a section of the wall on which a gutter, B, is hung, formed from one piece of metal, as shown from *a* to *b* to *c*. On top of this the metal curb C is soldered, which is also formed from one piece with a lock seam at *i*. To stiffen this curb a wooden core is slipped inside as shown at D. From the inside condensation gutter *f* a 14-oz. copper tube runs through the curb, shown at *d*. The condensation from the gutter *e* in the bar, drips into the gutter *f*, out of the tube *d*, into the main gutter B, from which it is conveyed to the outside by a leader.

In Fig. 163 is shown an enlarged section of a raising sash, taken through C D in Fig. 155. A in Fig. 163 shows the ridge bar, B the lower curb and C D the side sections of the bars explained in connection with Fig. 156. E F in Fig. 163 shows the upper frame of the raising sash, fitting onto the half ridge bar A. On each raising sash, at the upper end two hinges H are riveted at E and I, which allow the sash to raise or close by means of a cord, rod, or gearings. J K shows the lower frame of the sash fitting over the curb B. Holes are punched at *a* to allow the condensation to escape into *b*, thence to the outside through C. Over the hinge H a hood or cap is placed which prevents leakage. Fig. 164 shows a section through A B in Fig. 167 and represents a hipped skylight having one-third pitch. By a skylight of one-third pitch is meant a skylight whose altitude or height A B, is equal to one-third of the span C D. If the skylight was to have a pitch of one-fourth or one-fifth, then the altitude A B would equal one-fourth or one-fifth respectively of the span C D.

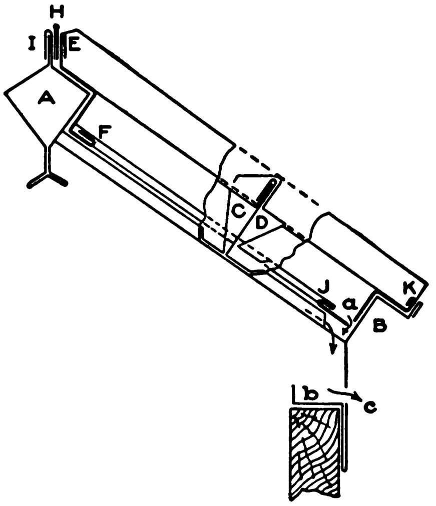


Fig. 163.

The illustration shows the construction of a hipped skylight with ridge ventilator which will be briefly described. C D is the curb; E E the inside ventilator; F F the outside ventilator forming a cap over the glass at *a*. G shows the hood held in position by two cross braces H. J represents a section of the common bar on the rabbets of which the glass K K rests. L shows the condensation gutters on the bar J,

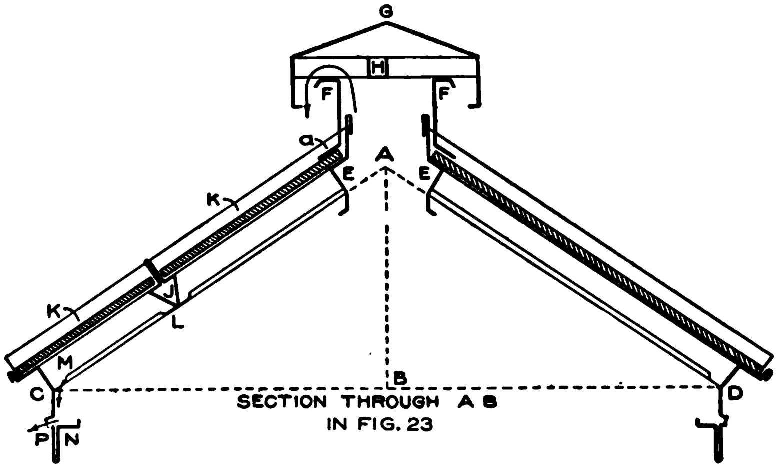


Fig. 164.

which are notched out as shown at M, thus allowing the drip to enter the gutter N and discharge through the tube P. The foul air escapes under the hood G as shown by the arrow.

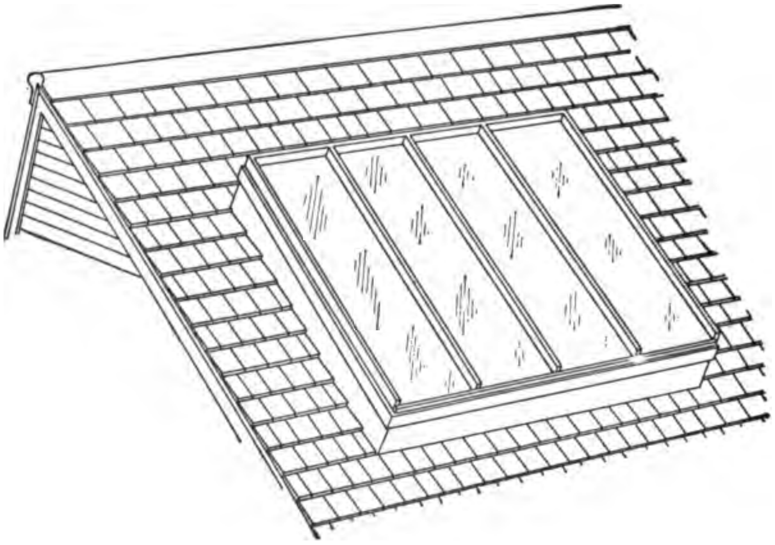


Fig. 165.

VARIOUS STYLES OF SKYLIGHTS

In Fig. 165 is shown what is known as a single-pitch light, and is placed on a curb made by the carpenter which has the desired pitch.

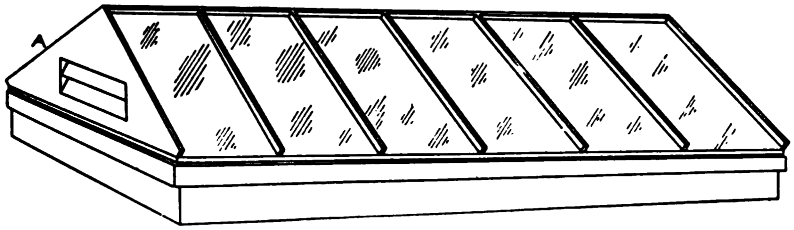


Fig. 166.

These skylights are chiefly used on steep roofs as shown in the illustration, and made to set on a wooden curbs pitching the same as the roof, the curb first being flashed. Ventilation is obtained by raising one or more lights by means of gearings, as shown in Fig. 155.

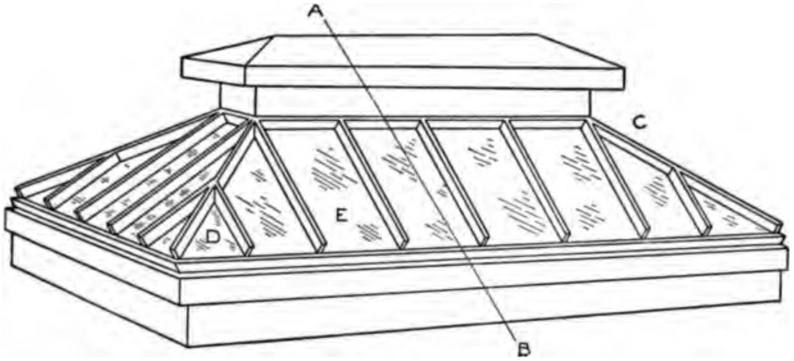


Fig. 167.

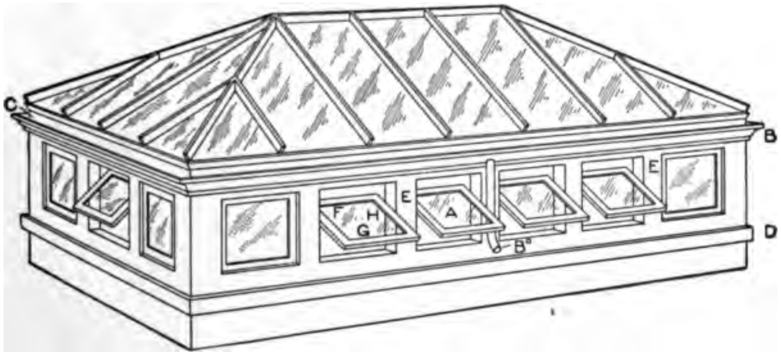


Fig. 168.

Fig. 166 shows a double-pitch skylight. Ventilation is obtained by placing louvres at each end as shown at A. Fig. 167 shows a skylight with a ridge ventilator. The corner bar C is called the hip bar; the small bar D, mitering against the corner bar, is called the jack bar, while E is called the common bar. Fig. 168 illustrates a hip monitor skylight with glazed opening sashes for ventilation. These sashes can be opened or closed separately, by means of gearings similar to those shown in Fig. 177 In Fig. 169 is shown the method of raising sashes in conservatories, greenhouses, etc., the same apparatus being applicable to both metal and wooden sashes. Fig. 170 shows a view of a photographer's skylight; if desired, the vertical sashes can be made to open.

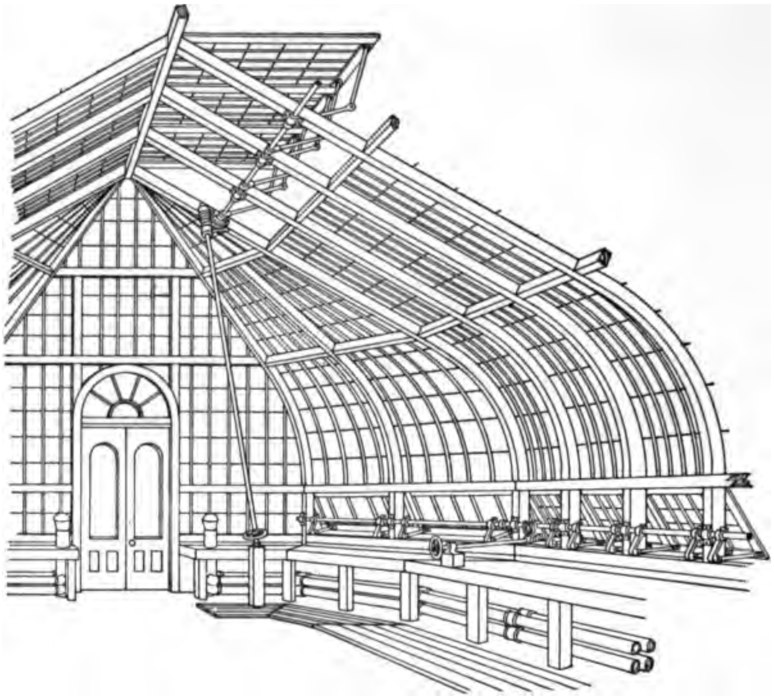


Fig. 169.

In Fig. 171 is shown a flat extension skylight at the rear of a store or building. The upper side and ends are flashed into the brick work and made water-tight with waterproof cement, while the lower side rests on the rear wall to which it is fastened. In some cases the rear gutter is of cast iron, put up by the iron worker, but it is usually made of No. 22 galvanized iron, or 20-oz. cold-rolled copper. To receive the bottom of the gutter and skylight, the wall should be covered by a wooden plate A, Fig. 172, about two inches thick, and another plank set edgeways flush with the inside of the wall, as shown at B. The two planks are not required when a cast iron gutter is used.

Fig. 173 shows a hipped skylight without a ridge ventilator, set on a metal curb in which louvres have been placed. These louvres may be made stationary or movable. When made movable, they are constructed as shown in Fig. 174, in which A shows a perspective view, B shows them closed, and C open. They are operated by the quadrants attached to the upright bars *a* and *b*, which in turn are pulled up and down by cords or chains worked from below. When a skylight has a very long span, as in Fig. 175, it is constructed as shown in Fig. 176, in which A represents a T-beam which can be trussed if necessary. This construction allows the water to escape from the bottom of the upper light to the outside of the top of the lower skylight, the curb C of the upper light fitting over the curb B of the lower light.

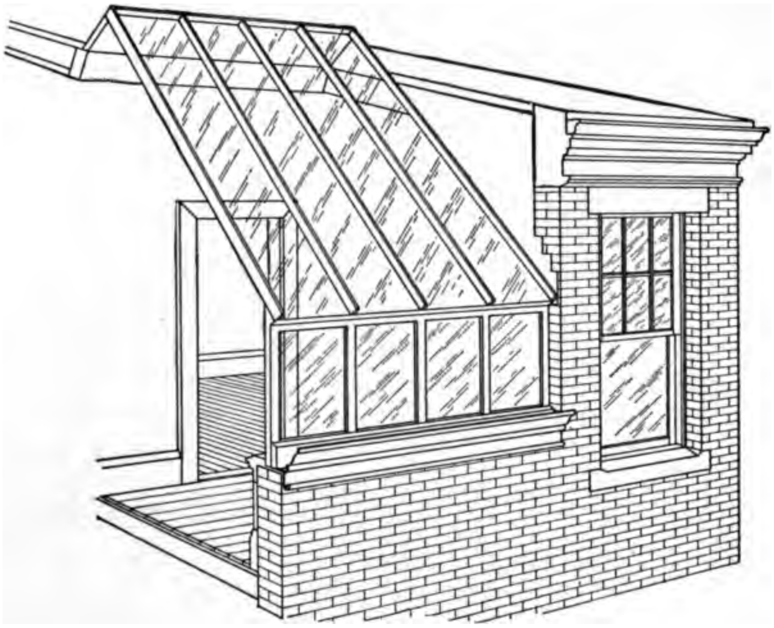


Fig. 170.

In Fig. 177 is shown the method of applying the gearings. A shows the side view of the metal or wooden sash partly opened, B the end of the main shaft, and C the binder that fastens the main shaft to the upright or rafter. D shows the quadrant wheel attached to main shaft and E is the worm wheel, geared to the quadrant D, communicating motion to the whole shaft. F is a hinged arm fastened to the main shaft B and hinged to the sash. By turning the hand-wheel the sash can be opened at any angle.

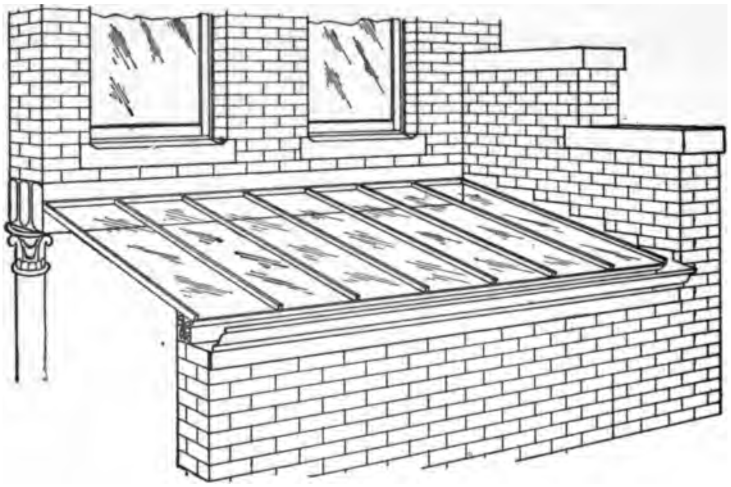


Fig. 171.

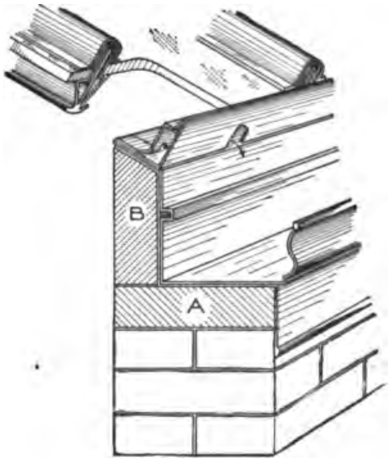


Fig. 172.

DEVELOPMENT OF PATTERNS FOR A HIPPED SKYLIGHT

The following illustrations and text will explain the principles involved in developing the patterns for the ventilator, curb, hip bar, common bar, jack bar, and cross bar or clip, in a hipped skylight. These principles are also applicable to any other form of light, whether flat, double-pitch, single-pitch, etc.

In Fig. 178 is shown a half section, a quarter plan, and a diagonal elevation of a hip bar, including the patterns for the curb, hip, jack, and common bars. The method of making these drawings will be explained in detail, so that the student who pays close attention will have no difficulty in laying out any patterns no matter what the pitch of the skylight may be, or what angle its plan may have.

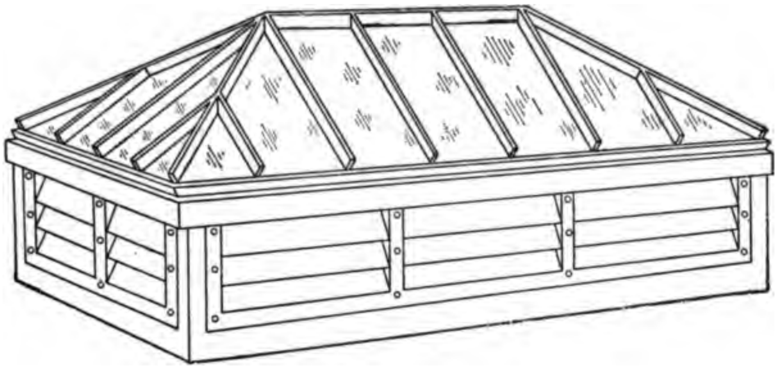


Fig 173

First draw any center line as A B, at right angles to which lay off C 4′, equal to 12 inches. Assuming that the light is to have one-third pitch, then make the distance C D equal to 8 inches which is one-third of 24 inches, and draw the slant line D 4.′ At right angles to D 4′ place a section of the common bar as shown by E, through which draw lines parallel to D 4′, intersecting the curb shown from *a* to *f* at the bottom and the inside section of the ventilator from F to G at the top. At

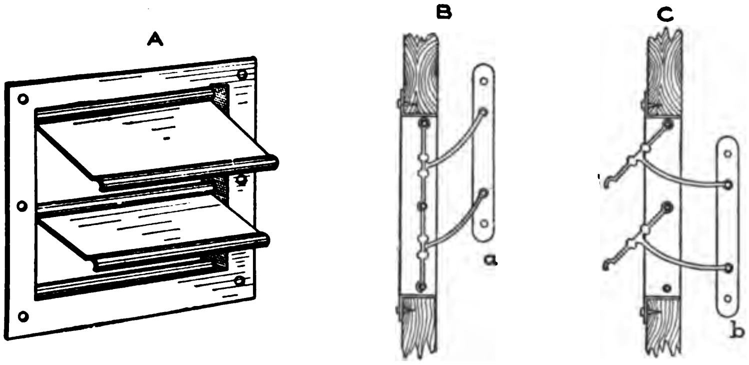


Fig. 174.

pleasure draw the section of the outside vent shown from *h* to *l* and the hood shown from *m* to *p*. X represents the section of the brace resting on *i j* to uphold the hood resting on it in the corner *o*. The condensation gutters of the common bar E are cut out at the bottom at 5′ 6′ which allows the drip to go into the gutter *d e f* of the curb and pass out of the opening indicated by the arrow. Number the corners of each half of the common bar section E as shown, from 1 to 6 on each side, through which draw lines parallel to D 4′ until they intersect the curb at the bottom as shown by similar numbers 1′ to 6′, and the inside ventilator at the top by similar figures 1″ to 6″. This completes the one half-section of the skylight. From this section the pattern for the common bar can be obtained without the plan, as follows:

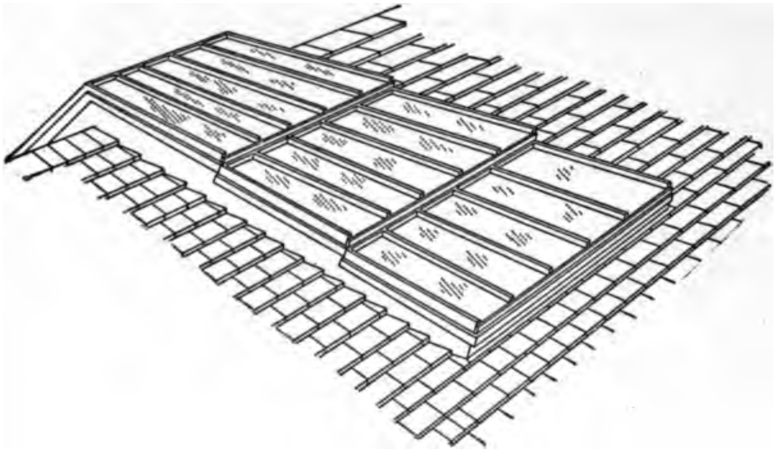


Fig. 175.

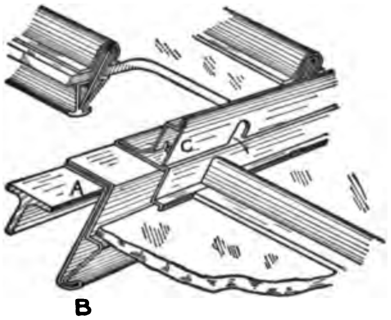


Fig. 176.

At right angles to D 4′ draw the line I J upon which place the stretchout of the section E as shown by similar figures on I J. Through these small figures, and at right angles to I J, draw lines, and intersect them by lines drawn at right angles to D 4′ from similarly numbered intersections 1′ to 6′ on the curb and 1″ to 6″ on the inside ventilator. Trace a line through points thus obtained; then A^1 B^1 C^1 D^1 will be the pattern for the common bar in a hipped skylight. The same method would be employed if a pattern were developed for a flat or a double-pitch light. From this same half section the pattern for the curb is developed by taking the stretchout of the various corners in the curb, *a b* 3′ 4′ *c d e* and *f*, and placing them on the center line A B as shown by similar letters and figures. Through these divisions and at right angles to A B draw lines which intersect with lines drawn at right angles to C 4′ from similar points in the curb section *a f*. Trace a line through points thus obtained; then E^1 F^1 *f a* will be the half pattern for the curb shown in the half section. V represents the condensation hole to be punched into the pattern between each light of glass in the skylight. As the portion *c d* turns up on *c* 4′, use *r* as a center, and with the radius *r s* strike the semicircle shown. Above this semicircle punch the hole V.

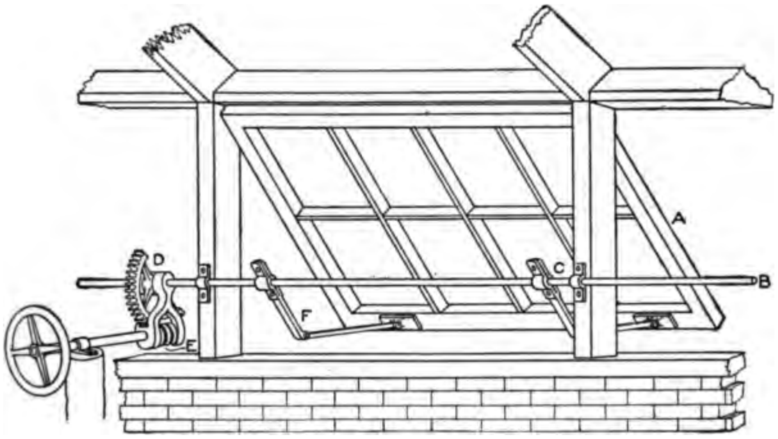


Fig. 177.

Before the patterns can be obtained for the hip and jack bars, a quarter plan view must be constructed which will give the points of intersections between the hip bar and curb, between the hip bar and vent, or ridge bar, and between the hip and jack bar. Therefore, from any point on the center line A B as K, draw K L at right angles to A B. As the skylight forms a right angle in plan, draw from K, at an angle of 45°, the hip or diagonal line K 1°. Take a tracing of the common bar section E with the various figures on same, and place it on the hip line K 1° in plan so that the points 1 4 come directly on the hip as shown by E^1. Through the various figures draw lines parallel to K 1°

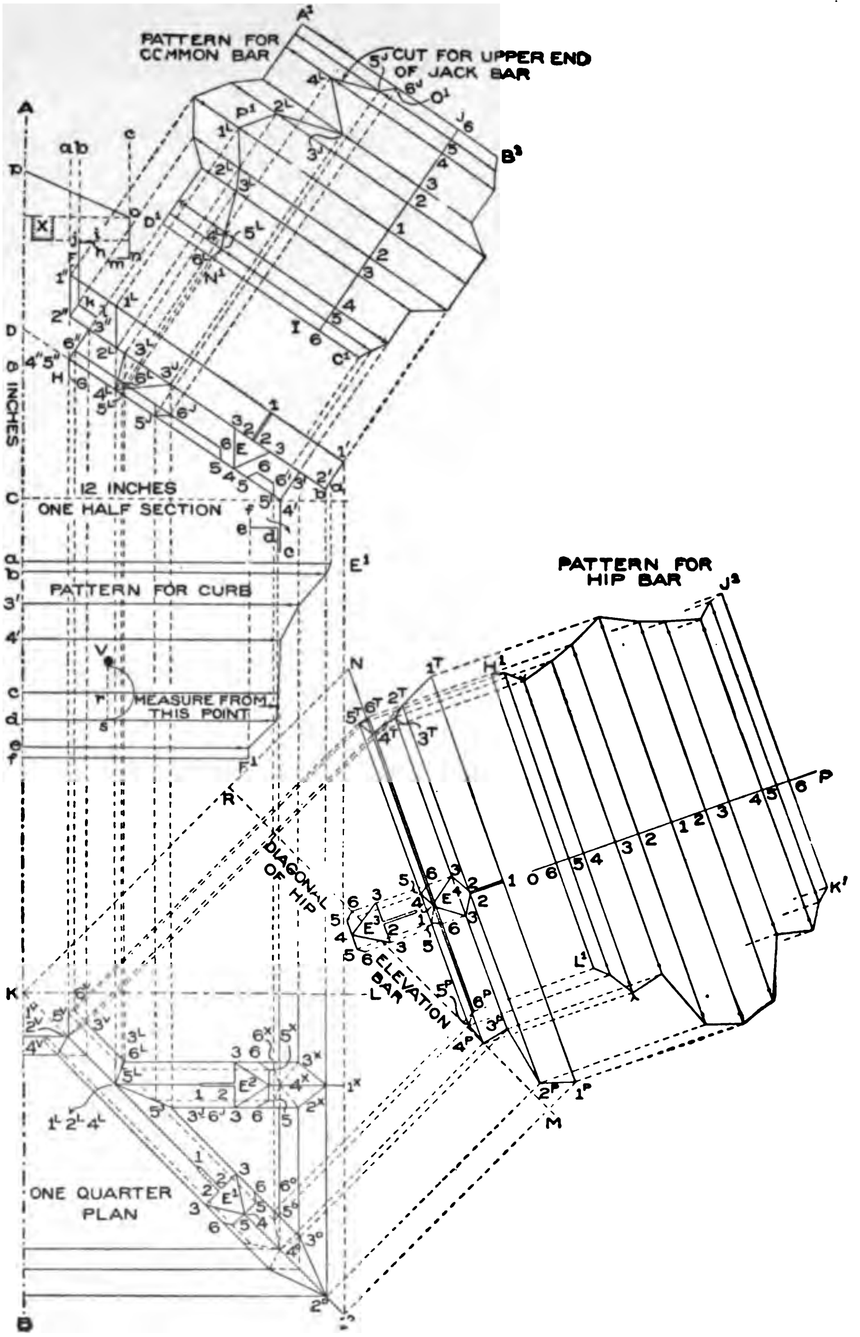

PATTERN FOR COMMON BAR
CUT FOR UPPER END OF JACK BAR
A
A¹
B¹
C¹
D¹
N¹
O¹
P¹
D
6 INCHES
12 INCHES
C
ONE HALF SECTION
E¹
PATTERN FOR CURB
V
MEASURE FROM THIS POINT
F¹
N
R
DIAGONAL OF HIP
ELEVATION BAR
PATTERN FOR HIP BAR
J³
H¹
P
K¹
L¹
M
K
L
ONE QUARTER PLAN
B

Fig. 178.

one-half of which are intersected by vertical lines drawn parallel to A B from similar points of intersection $1'$ to $6'$ on the curb, and $1''$ to $6''$ on the ventilator in the half section, as shown respectively in plan by intersections 1° to 6° and 1^{V} to 6^{V}. Below the hip line K 1° trace the opposite intersection as shown. It should be understood that the section E^1 in plan does not indicate the true profile of the hip bar (which must be obtained later), but is only placed there to give the horizontal distances in plan. In laying out the work in practice to full size, the upper half intersection of the hip bar in plan is all that is required. It will be noticed that the points of intersections in plan and one half section have similar numbers, and if the student will carefully follow each point the method of these projections will become apparent.

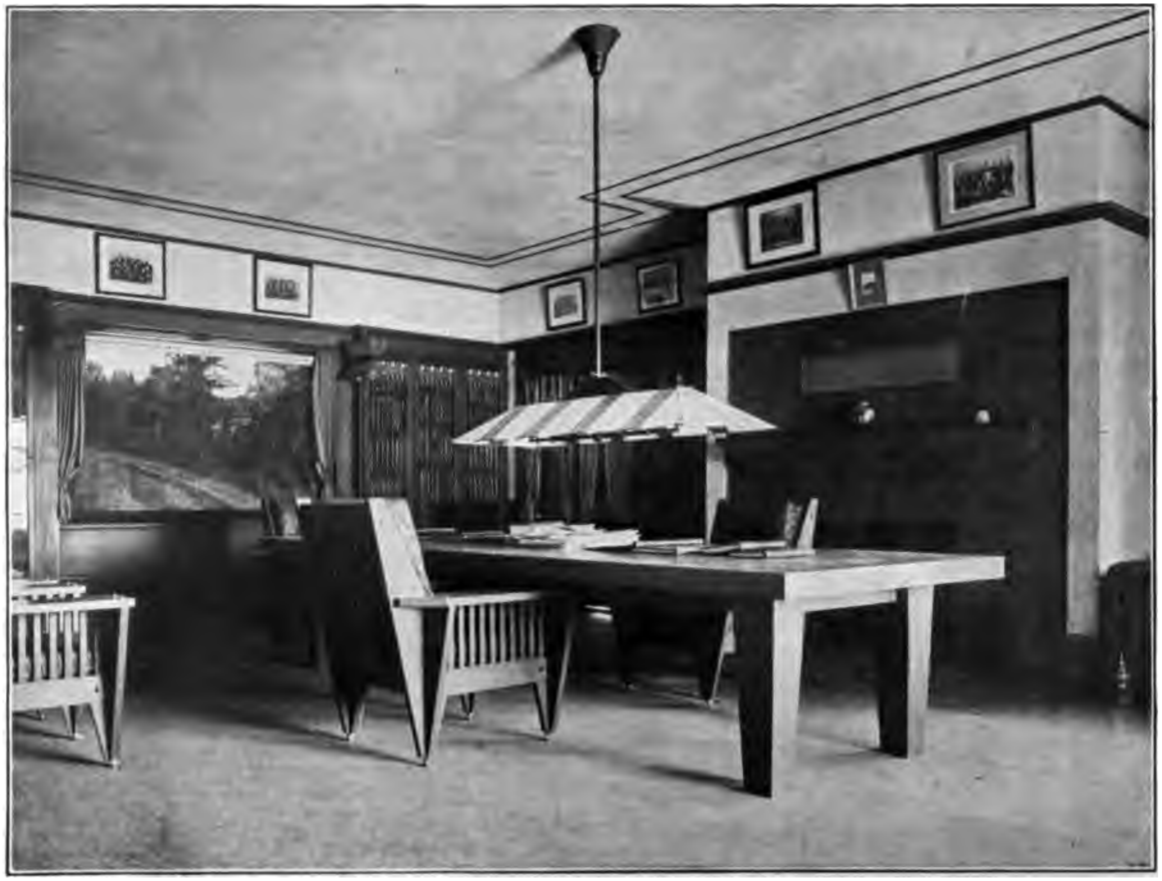
Having obtained the true points of intersections in plan the next step is to obtain a diagonal elevation of the hip bar, from which a true section of the hip bar and pattern are obtained. To do this draw any line as R M parallel to K 1°. This base line R M has the same elevation as the base line C $4'$ has in the half section. From the various points 1° to 6° and 1^{V} to 6^{V} in plan, erect lines at right angles to K 1° crossing the line R M indefinitely. Now measuring in each and every instance from the line C $4'$ in the half section take the various distances to points D $1''$ $2''$ $3''$ $4''$ $5''$ and $6''$ at the top, and to points $1'$ $2'$ $3'$ $4'$ $5'$ and $6'$ at the bottom, and place them in the diagonal elevation measuring in each and every instance from the line R M on the similarly numbered lines drawn from the plan, thus locating respectively the points N 1^{T} 2^{T} 3^{T} 4^{T} 5^{T} and 6^{T} at the top, and 1^{P} 2^{P} 3^{P} 4^{P} 5^{P} and 6^{P} at the bottom. Through the points thus obtained draw the miter lines 1^{T} to 6^{T} and 1^{P} to 6^{P} and connect the various points by lines as shown, which completes the diagonal elevation of the hip bar intersecting the curb and vent, or ridge. To obtain the true section of the hip bar, take a tracing of the common bar E or E^1 and place it in the position shown by E^3, being careful to place the points 1 4 at right angles to 1^{T} 1^{P} as shown. From the various points in the section E^3 at right angles to 1^{P} 1^{T} draw lines intersecting similarly numbered lines in the diagonal elevation as shown from 1 to 6 on either side. Connect these points as shown; then E^4 will be the true profile of the hip bar. Note the difference in the two profiles; the normal E^3 and the modified E^4.

Having obtained the true profile E^4 the pattern for the hip bar is obtained by drawing the stretchout line O P at right angles 1^{T} 1^{P}.

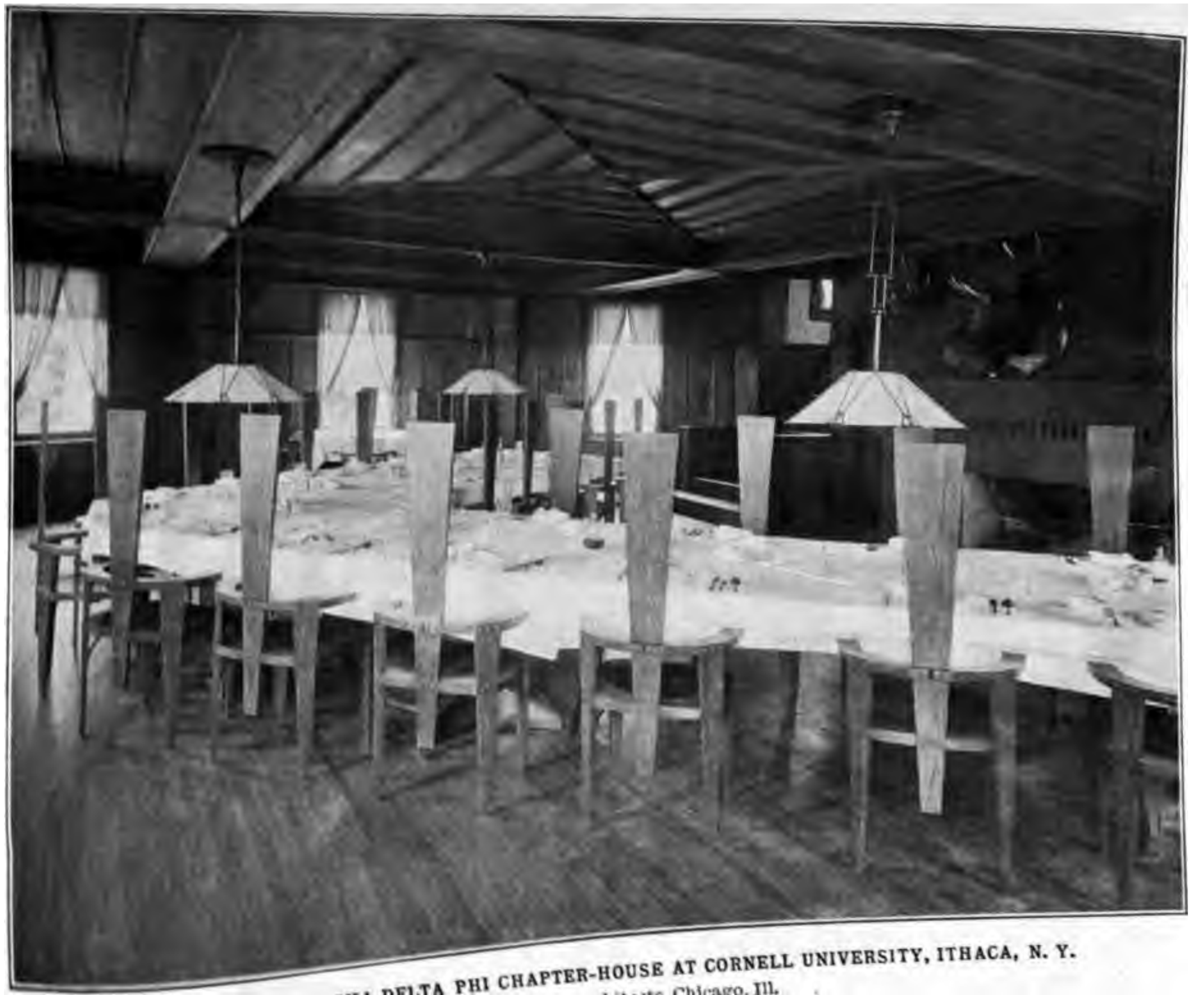
Take the stretchout of the profile E^4 and place it on O P as shown by similar figures. Through these small figures and at right angles to O P draw lines which intersect by lines drawn at right angles to 1^T 1^P from similarly numbered points at top and bottom, thus obtaining the points of intersections shown. A line traced through the points thus obtained, as shown by H^1 J^1 K^1 L^1 will be the pattern for the hip bar.

For the pattern for the jack bar, take a tracing of the section of the common bar E and place it in the position in plan as shown by E^2 being careful to have the points 1 and 4 at right angles to the line 1^X 1°. It is immaterial how far the section E^2 is placed from the corner 2° as the intersection with the hip bar remains the same no matter how far the section is placed one way or the other. Through the various corners in the section E^2 draw lines at right angles to the line 1° 1^X intersecting one half of the hip bar on similarly numbered lines as shown by the intersections 1^L 2^L 3^L 4^L 5^L 6^L and 1^L 2^J 3^J 4^L 5^J and 6^J; also intersecting the curb in plan at points 1^X to 6^X. The intersection between the jack bar and curb in plan is not necessary in the development of the pattern as the lower cut in the pattern for the common bar is the same as the lower cut in the pattern for the jack bar. However, the intersection is shown in plan to make a complete drawing. At right angles to the line of the jack bar in plan, and from the various intersections with the hip bar, erect lines intersecting similarly numbered lines in the section as shown. Thus from the various intersections shown from 1^L to 6^L in plan, erect vertical lines intersecting the bar in the half section at points shown from 1^L to 6^L. In similar manner from the various points of intersections 3^J, 5^J, and 6^J in plan, erect lines intersecting the bar in the half section at points shown by 3^J 5^J 6^J. Connect these points in the half section, as shown, which represents the line of joint in the section between the hip and jack bars.

For the pattern for the upper cut of the jack bar, the same stretchout can be used as that used for the common bar. Therefore, at right angles to D 4′ and from the various intersections 1^L 2^L 3^L 4^L 5^L and 6^L draw lines intersecting similar numbered lines in the pattern for the common bar as shown by similar figures. In similar manner from the various intersections 3^J 5^J and 6^J in the one half section, draw lines at right angles to D 4′ intersecting similarly numbered lines in the pattern as shown by 3^J 5^J and 6^J. Trace lines from point to point, then the



LIBRARY IN ALPHA DELTA PHI CHAPTER-HOUSE AT CORNELL UNIVERSITY, ITHACA, NEW YORK
Dean and Dean, Architects, Chicago, Illinois



DINING ROOM IN ALPHA DELTA PHI CHAPTER-HOUSE AT CORNELL UNIVERSITY, ITHACA, N. Y.

Dean & Dean, Architects, Chicago, Ill.

Oak Woodwork Stained a Dark Venetian Red; Mantel, Akron Roman Brick. Furniture Designed by Architects: Stained to Match the Woodwork.

cut shown from N^1 to P^1 will represent the miter for that part shown in plan from 2^L to 6^L, and the cut shown from P^1 to O^1 in the pattern will represent the cut for that part shown in plan from 2^L to 6^J. The lower cut of the jack bar remains the same as that shown in the pattern.

The half pattern for the end of the hood is shown in Fig. 179, and is obtained as follows: Draw any vertical line as A B, upon which place the stretchout of the section of the hood *m n o p* in Fig. 178, as shown by similar letters *m n o p* on A B in Fig. 179. At right angles to A B and through the small letters draw lines, making them equal in length, (measuring from the line A B) to points having similar letters in Fig. 178, also measuring from the center line A B. Connect points shown in Fig. 179, which is the half pattern for the end of the hood. For the half pattern for the end of the outside ventilator, take the stretchout of *h i j k l* in Fig. 178 and place it on the vertical line A B in Fig. 180 as shown by similar letters, through which draw horizontal lines making them in length, measuring from A B, equal to similar letters in Fig. 178, also measuring from the center line A B. Connect the points as shown in Fig. 180 which is the desired half pattern. In Fig. 181 is shown the half pattern for the end of the inside ventilator, the stretchout of which is obtained from F 1″ 2″ 3″ 4″ H G in Fig. 178, the pattern being obtained as explained in connection with Figs. 179 and 180.

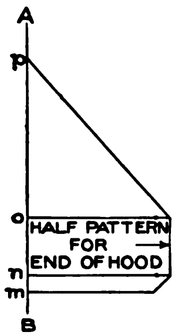


Fig. 179.

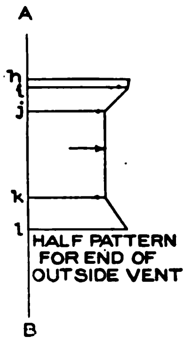


Fig. 180.

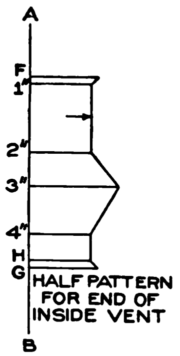


Fig. 181.

When a skylight is to be constructed on which the bars are of such lengths that the glass cannot be obtained in one length, and a cross bar or clip is required as shown by B, in Fig. 150, which miters against the main bar, the pattern for this intersecting cut is obtained as shown in

Fig. 182. Let A represent the section of the main bar, B the elevation of the cross bar, and C its section. Note how this cross bar is bent so that the water follows the direction of the arrow, causing no leaks because the upper glass *a* is bedded in putty, while the lower light *b* is capped by the top flange of the bar C (See Fig. 150). Number all of the corners of the section C as shown, from 1 to 8, from which points draw horizontal lines cutting the main bar A at points 1 to 8 as shown. At right angles to the lines in B draw the vertical line D E upon which place the stretchout of the cross bar C, shown by similar figures, through which draw horizontal lines, intersecting them with lines drawn parallel to D E from similar numbered intersections against the main bar A, thus obtaining the points of intersections 1′ to 8′ in the pattern. Trace a line through points of intersections thus obtained which will be the pattern for the end cut of the cross bar.

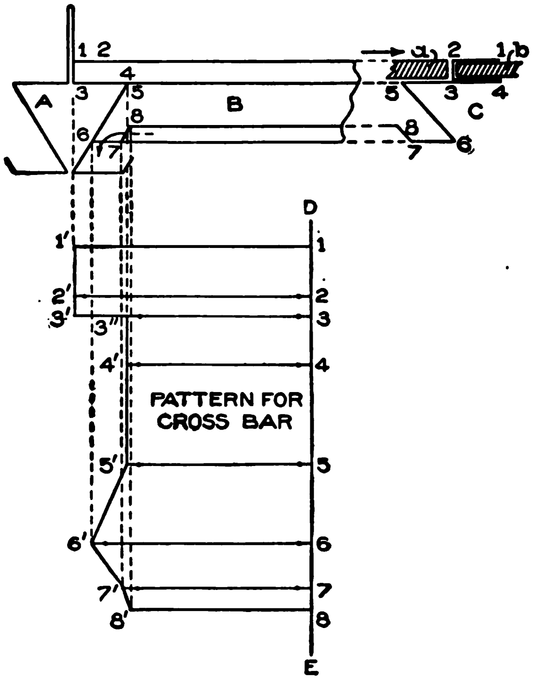


Fig. 182.

In Fig. 183 is shown a carefully drawn working section of the turret sash shown in Fig. 168 at A. These sashes are operated by means of cords, chains or gearings from the inside, the pivot on which they turn being shown by R S in Fig. 183. The method of obtaining the patterns for these sashes will be omitted, as they are only square and butt miters which the student will have no trouble in developing, providing he understands the construction. This will be made clear by the following explanation:

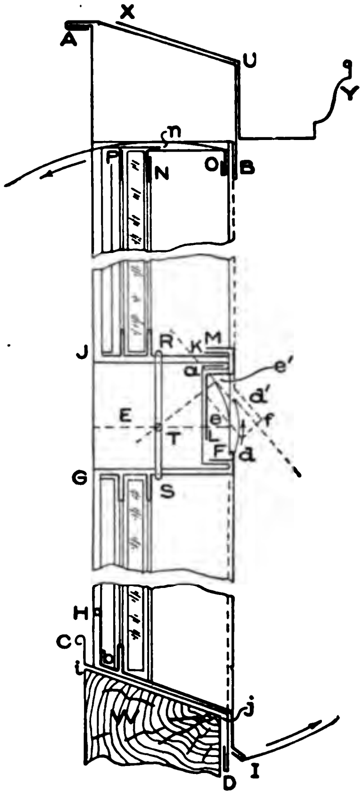


Fig. 183.

A B represents the upper part of the turret proper with a drip bent on same, as shown at B, against which the sashes close, and a double seam, as shown at A, which makes a tight joint, takes out the twist in bending, and avoids any soldering. This upper part A B is indicated by C in Fig. 168, over which the gutter B is placed as shown by X U Y in Fig. 183. C D represents the lower part of the turret proper or base, which fits over the wooden curb W, and is indicated by D in Fig. 168. E in Fig. 183 represents the mullion made from one piece of metal and double seamed at *a*. This mullion is joined to the top and bottom. The pattern for the top end of the mullion would simply show a square cut, while the pattern for the bottom would represent a butt miter against the slant line *i j*. Before forming up this mullion the holes should be punched in the sides to admit the pivot R S. These mullions are shown in position in Fig. 168 by E E, etc.

F G in Fig. 183 represents the section of the side of the sash below the pivot T. Notice that this lower half of the side of the sash has a lock attachment which hooks into the flange of the mullion E at F. While the side of the sash is bent in one piece, the upper half, above the pivot T, has the lock omitted as shown by J K. Thus when the sash opens, the upper half of the sides turn toward the inside as shown by the arrow at the top, while the lower half swings outward as shown by the arrow at the bottom. When the lower half closes, it locks as shown at F, which makes a water-tight joint; but to obtain a water-tight joint for the upper half, a cap is used, partly shown by L M, into which the upper half of the side of the sash closes as shown at M. This cap is fastened to the upper part of the mullion E with a projecting hood *f* which is placed at the same angle as the sash will have when it is opened as shown by *e e′* and *d d′* or by the dotted lines.

The side of the sash just explained is shown in Fig. 168 at H. The pattern for the side of the sash has a square cut at the top, mitering with H I at the bottom, in Fig. 183, the same as a square miter. H I represents the section of the bottom of the sash. Note where the metal is doubled as at *b*, against which the glass rests in line with the rabbet on the side of the sash. A beaded edge is shown at H which stiffens it. This lower section is shown in Fig. 168 by G and has square cuts on both ends. N O in Fig. 183 shows the section of the top of the sash shown in Fig. 168 by F. The flange N in Fig. 183 is flush with the outside of the glass, thereby allowing the glass to slide into the grooves in the sides of the sash. After the glass is in position the angle P is tacked at *n*. A leader is attached to the gutter Y as shown by B° in Fig. 168. While the method of construction shown in Fig. 183 is generally employed, each shop has different methods; what we have aimed to give is the general construction in use, after knowing which, the student can plan his own construction to suit the conditions which are apt to arise.

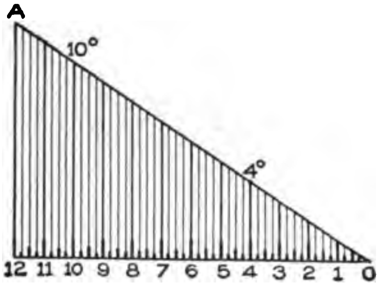


Fig. 184.

In the following illustrations, Figs. 184 to 187, it will be explained how to obtain the true lengths of the ventilator, ridge, hip, jack, and common bars in a hipped skylight, no matter what size the skylight may be. Using this rule only one set of patterns are required, as for example, those developed in connection with Figs. 178, 179, 180, and 181, which in this case has one-third pitch. If, however, a skylight was required whose pitch was different than one-third, a new set of patterns would have to be developed, to which the rule above mentioned would also be applicable for skylights of that particular pitch. Using this rule it should be understood that the size of the curb, or frame, forms the basis for all measurements, and that one of the lines or bends of the bar should meet the line of the curb as shown in Fig. 178, where the bottom of the bar E in the half section meets the line of the curb *c* 4′ at 4′, and the ridge at the top at 4′. Therefore when laying out the lengths of the bars, they would have to be measured on the line 4 of the bar E from 4′ to 4″ on the patterns, as will be explained as we proceed.

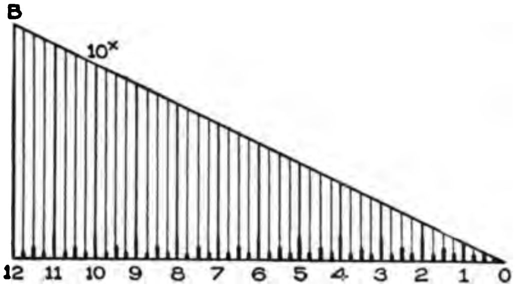


Fig. 185.

The first step is to prepare the triangles from which the lengths of the common and jack bars are obtained, also the lengths of the hip bars. After the drawings and patterns have been laid out full size according to the principles explained in Fig. 178, take a tracing of the triangle in the half section D C 4′ and place it as shown by A 12 O, in Fig. 184. Divide O 12, which will be 12 inches in full size, into quarter, half-inches, and inches, the same as on a 2-foot rule, as shown by the figures O to 12. From these divisions erect lines until they intersect the pitch A O which completes the triangle for obtaining the true lengths of jack and common bars for any size skylight. In similar manner take tracing of N R 4ʳ in the diagonal elevation in Fig. 178 and place it as shown by B 12 O in Fig. 185. The length 12 O then becomes the base of the triangle for the hip bar in a skylight whose base of the triangle for the common and jack bars measures 12 inches

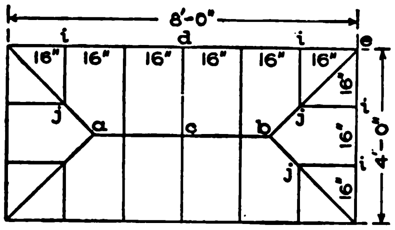


Fig. 186.

as shown in Fig. 184, the heights A 12 in Fig. 184 and B 12 in Fig. 185 being equal. Now divide 12 O in 12 equal spaces which will represent inches when obtaining the measurements for the hip bar. Divide each of the parts into quarter-inches as shown. From these devisions erect lines intersecting the hypothenuse or pitch line B O as shown.

To explain how these triangles are used in practice, Figs. 186 and 187 have been prepared, showing respectively a skylight without and with a ventilator whose curb measures 4 ft. x 8 ft. Three rules are used in connection with the triangles in Figs. 184 and 185, the comprehension of which will make clear all that follows.

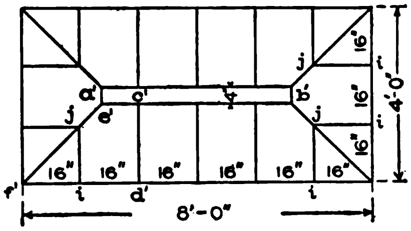


Fig. 187.

Rule 1. To obtain the length of the ridge bar in a skylight without a ventilator, as in Fig. 186, deduct the short side of the frame or curb from the long side.

Example: In Fig. 186, take 8 feet (long side of frame) — 4 feet (short side of frame) = 4 feet (length of ridge bar *a b*).

Rule 2. To find the length of the ventilator in a skylight deduct the short side of the frame from the long side and add the width of the desired ventilator (in this case 4 inches, as shown in Fig. 187).

Example: In Figure 187 take 8 feet (long side of frame) — 4 feet (short side of frame) = 4 feet. 4 feet + 4 inches (width of inside ventilator) = 4 feet 4 inches, (length of inside ventilator *a' b'*). To find the size of the outside ventilator *h l* and hood *m p* in Fig. 178 simply add twice the distance *a b* and *a c* respectively to the above size, 4 inches, and 4 feet 4 inches, which will give the widths and lengths of the outside vent and hood.

Rule 3. To find the lengths of either common or hip bar (in any size skylight) deduct the width of the ventilator, if any, from the length of the shortest side of frame and divide the remainder by two. Apply the length thus obtained on the base line of its respective triangle for common or hip bars and determine the true lengths of the desired bars, from the hypothenuse.

Example: As no ventilator is shown in Fig. 186, there will be nothing to deduct for it, and the operation is as follows: 4 feet (shortest side of frame) ÷ 2 = 2 feet. We have now the length with which to proceed to the triangle for common and hip bars. Thus the length of the common bar *c d* will be equal to twice the amount of A O in Fig. 184, while the length of the hip bar *b e* in Fig. 186, will be equal to twice the amount of B O in Fig. 185. Referring to Figs. 186 and 187 the jack bars *i j* are spaced 16 inches, therefore, the length of the jack bar for 12 inches will equal A O in Fig. 184, and 4 inches equal to 4° O; both of which are added together for the full length.

The lengths of the common and hip bars will be shorter in Fig. 187 because a ventilator has been used, while in Fig. 186 a ridge bar was employed. To obtain the lengths of the common and hip bars in Fig. 187 use Rule 3: 48 inches (length of short side) − 4 inches (width of inside ventilator) = 44 inches; and 44 inches ÷ 2 = 22 inches or 1 foot 10 inches. Then the length of the common bar *c′ d′* measured with a rule will be equal to A O in Fig. 184 and 10° O added together, and the length of the hip bar *e′ f′* in Fig. 187 will be equal to B O in Fig. 185 and 10^{x} O added together. Use the same method where fractional parts of an inch occur. In laying out the patterns according to these measurements use the cuts shown in Figs. 178, 179, 180, and 181, being careful to measure from the arrowpoints shown on each pattern.

It will be noticed in Fig. 178 we always measure on line 4 in the patterns for the hip, common, and jack bars. This is done because the line 4 in the profiles E and E^4 come directly on the slant line of the triangles which were traced to Figs. 184 and 185 and from which the true lengths were obtained. Where a curb might be used, as shown in Fig. 188, which would bring the bottom line of the bar 1½ inches toward the inside of the frame *b*, all around, then instead of using the size of 4 x 8 feet as the basis of measurements deduct 3 inches on each side, making the basis of measurements 3 ft. 9 inches x 7 ft. 9 inches, and proceed as explained above.

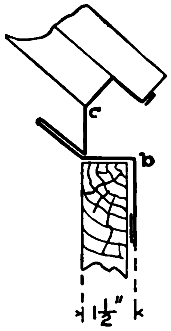


Fig. 188.

ROOFING

A good metal covering on a roof is as important as a good foundation. There are various materials used for this purpose such as terne plate or what is commonly called roofing tin. The rigid body, or the base of roofing tin, consists of thin sheets of steel (black plates) that are coated with an alloy of tin and lead. Where a first-class job is desired soft and cold rolled copper should be used. The soft copper is generally used for cap flashing and allows itself to be dressed down well after the base flashing is in position. The cold-rolled or hard copper is used for the roof coverings. In some cases galvanized sheet iron or steel is employed. No matter whether tin, galvanized iron, or copper is employed the method of construction is the same, and will be explained as we proceed.

Another form of roofing is known as corrugated iron roofing, which consists of black or galvanized sheets, corrugated so as to secure strength and stiffness. Roofs having less than one-third pitch should be covered by what is known as flat-seam roofing, and should be covered (when tin or copper is used) with sheets 10 x 14 inches in size rather than with sheets 14 x 20 inches, because the larger number of seams stiffens the surface and prevents the rattling of the tin in stormy weather. Steep roofs should be covered by what is known as standing-seam roofing made from 14″ x 20″ tin or from 20″ x 28″. Before any metal is placed on a roof the roofer should see that the sheathing boards are well seasoned, dry and free from knots and nailed close together. Before laying the tin plate a good building paper, free from acid, should be laid on the sheathing, or the tin plate should be painted on the underside before laying. Corrugated iron is used for roofs and sides of buildings. It is usually laid directly upon the purlins in roofs, and held in place by means of clips of hoop iron, which encircle the purlins and are riveted to the corrugated iron about 12 inches apart. The method of constructing flat and double-seam roofing, also corrugated iron coverings, will be explained as we proceed.

TABLES

The following tables will prove useful in figuring the quantity of material required to cover a given number of square feet.

FLAT-SEAM ROOFING

Table showing quantity of 14 x 20-inch tin required to cover a given number of square feet with flat seam tin roofing. A sheet of 14 x 20 inches with with ½-inch edges measures, when edged or folded, 13 x 19 inches or 247 square inches. In the following all fractional parts of a sheet are counted a full sheet.

No. of sq. ft.	Sheets required	No. of sq. ft.	Sheets required	No. of sq. ft.	Sheets required	No. of sq. ft.	Sheets required
100	59	330	193	560	327	780	455
110	65	340	199	570	333	790	461
120	70	350	205	580	339	800	467
130	76	360	210	590	344	810	473
140	82	370	216	600	350	820	479
150	88	380	222	610	356	830	484
160	94	390	228	620	362	840	490
170	100	400	234	630	368	850	496
180	105	410	240	640	374	860	502
190	111	420	245	650	379	870	508
200	117	430	251	660	385	880	514
210	123	440	257	670	391	890	519
220	129	450	263	680	397	900	525
230	135	460	269	690	403	910	531
240	140	470	275	700	409	920	537
250	146	480	280	710	414	930	543
260	152	490	286	720	420	940	549
270	158	500	292	730	426	950	554
280	164	510	298	740	432	960	560
290	170	520	304	750	438	970	566
300	175	530	309	760	444	980	572
310	181	540	315	770	449	990	578
320	187	550	321				

1000 square feet, 583 sheets.

A box of 112 sheets 14 x 20 inches will cover approximately 192 square feet.

Example. How much 14 x 20 inch tin with ½-inch edges is required to cover a roof 20 feet x 84 feet? Take 20 × 84 = 1,680 square feet.

Referring to the table for Flat Seam Roofing, 1000 square feet require 583 sheets and 680 square feet require 397 sheets, making a total of 980 sheets.

It should be understood that this amount is figured on the basis of 247 square inches in an edged sheet, which will be a trifle less when the sheets are laid on the roof.

Example. What quantity of 20 x 28-inch tin will be required to lay a standing seam roof, measuring 37 feet long x 45 feet in width? Take 37 × 45 = 1,665 square feet, or 16 squares and 65 feet. Referring to the table for Standing Seam Roofing, 16 squares require 4 boxes and 48 sheets, and 65 feet require 20 sheets, making a total of 4 boxes and 68 sheets.

STANDING-SEAM ROOFING

Table showing the quantity of 20 × 28-inch tin in boxes, and sheets required to lay any given standing-seam roof.

SQ. FEET	SHEETS	SQUARES	SQ. FEET	BOXES	SHEETS	SQUARES	BOXES	SHEETS
1	1	......	68	......	21	35	9	77
2	1	......	69	......	21	36	9	108
3	1	......	70	......	22	37	10	27
4	2	......	71	......	22	38	10	58
5	2	......	72	......	22	39	10	89
6	2	......	73	......	22	40	11	8
7	3	......	74	......	23	41	11	39
8	3	......	75	......	23	42	11	70
9	3	......	76	......	23	43	11	101
10	4	......	77	......	24	44	12	20
11	4	......	78	......	24	45	12	51
12	4	......	79	......	24	46	12	82
13	4	......	80	......	25	47	13	1
14	5	......	81	......	25	48	13	32
15	5	......	82	......	25	49	13	63
16	5	......	83	......	25	50	13	94
17	6	......	84	......	26	51	14	13
18	6	......	85	......	26	52	14	44
19	6	......	86	......	26	53	14	75
20	7	......	87	......	27	54	14	106
21	7	......	88	......	27	55	15	25
22	7	......	89	......	27	56	15	56
23	7	......	90	......	28	57	15	87
24	8	......	91	......	28	58	16	6
25	8	......	92	......	28	59	16	37
26	8	......	93	......	28	60	16	68
27	9	......	94	......	29	61	16	99
28	9	......	95	......	29	62	17	18
29	9	......	96	......	29	63	17	49
30	10	......	97	......	30	64	17	80
31	10	......	98	......	30	65	17	111
32	10	......	99	......	30	66	18	30
33	10	......	100	......	31	67	18	61
34	11	1	......	......	31	68	18	92
35	11	2	......	......	62	69	19	11
36	11	3	......	......	93	70	19	42
37	12	4	......	1	12	71	19	73
38	12	5	......	1	43	72	19	104
39	12	6	......	1	74	73	20	23
40	13	7	......	1	105	74	20	54
41	13	8	......	2	24	75	20	85
42	13	9	......	2	55	76	21	4
43	13	10	......	2	86	77	21	35
44	14	11	......	3	5	78	21	66
45	14	12	......	3	36	79	21	97
46	14	13	......	3	67	80	22	16
47	15	14	......	3	98	81	22	47
48	15	15	......	4	17	82	22	78
49	15	16	......	4	48	83	22	109
50	16	17	......	4	79	84	23	28
51	16	18	......	4	110	85	23	59
52	16	19	......	5	29	86	23	90
53	16	20	......	5	60	87	24	9
54	17	21	......	5	91	88	24	40
55	17	22	......	6	10	89	24	71
56	17	23	......	6	41	90	24	102
57	18	24	......	6	72	91	25	21
58	18	25	......	6	103	92	25	52
59	18	26	......	7	22	93	25	83
60	19	27	......	7	53	94	26	2
61	19	28	......	7	84	95	26	33
62	19	29	......	8	3	96	26	64
63	19	30	......	8	34	97	26	95
64	20	31	......	8	65	98	27	14
65	20	32	......	8	96	99	27	45
66	20	33	......	9	15	100	27	76
67	21	34	......	9	46			

Size of sheet before working, 20 × 28 inches. Exposed on roof 27×17¾ inches.
Square inches per sheet exposed 479¼ inches. Sheets per box 112.

NET WEIGHT PER BOX TIN PLATES

Basis 14 × 20, 112

Trade term . . .		80-lb.	85-lb.	90-lb.	95-lb.	100-lb.	IC	IXL	IX	IXX	IXXX	IXXXX
Weight per box, lb.		80	85	90	95	100	107	128	135	155	175	195
Size of sheets	Sheets per box											
10 x 14	225	80	85	90	95	100	107	128	135	155	175	195
14 x 20	112	80	85	90	95	100	107	128	135	155	175	195
20 x 28	112	160	170	180	190	200	214	256	270	310	350	390
10 x 20	225	114	121	129	136	143	153	183	193	221	250	279
11 x 22	225	138	147	156	164	172	184	232	234	268	302	337
11½ x 23	225	151	161	170	179	189	202	242	255	293	331	368
12 x 12	225	82	87	93	98	103	110	132	139	159	180	201
12 x 24	112	82	87	93	98	103	110	132	139	159	180	201
13 x 13	225	97	103	109	115	121	129	154	163	187	211	235
13 x 26	112	97	103	109	115	121	129	154	163	187	211	235
14 x 14	225	112	119	126	133	140	150	179	189	217	245	273
14 x 28	112	112	119	126	133	140	160	179	189	217	245	273
15 x 15	225	129	137	145	153	161	172	206	217	249	281	313
16 x 16	225	146	155	165	174	183	196	234	247	283	320	357
17 x 17	225	165	175	186	196	206	221	264	279	320	361	403
18 x 18	112	93	98	104	110	116	124	148	156	179	202	226
19 x 19	112	103	110	116	122	129	138	165	174	200	226	251
20 x 20	112	114	121	129	136	143	153	183	193	221	250	279
21 x 21	112	126	134	142	150	158	169	202	213	244	276	307
22 x 22	112	138	147	156	164	172	184	221	234	268	302	337
23 x 23	112	151	161	170	179	189	202	242	255	298	331	368
24 x 24	112	164	175	185	195	204	220	263	278	319	360	401
26 x 26	112	193	205	217	229	241	258	309	326	374	422	471
16 x 20	112	91	97	103	109	114	122	146	154	177	200	223
14 x 31	112	124	132	140	147	155	166	198	209	240	271	302
11¼ x 22¾	112	73	78	82	87	91	98					
13¼ x 17¾	112	60	71	76	80	84	90					
13¼ x 19¼	112	73	77	82	87	91	97					
13½ x 19½	112	75	80	85	89	94	100					
13½ x 19¾	112	76	81	86	90	95	102					
14 x 18¾	124	83	88	93	98	103	110					
14 x 19¼	120	83	88	93	98	103	110					
14 x 21	112	84	89	95	100	105	112					
14 x 22	112	88	94	99	105	110	118					
14 x 22¼	112	89	95	100	106	111	119					
15½ x 23	112	102	108	115	121	127	136					

STANDARD WEIGHTS AND GAUGES OF TIN PLATES

Trade term	65-lb.	70-lb.	75-lb.	80-lb.	85-lb.	90-lb.	95-lb.	100-lb.
Nearest wire gauge No.	35	35	34	33	32	31	31	30
Weight, square foot, lb.	.298	.322	.345	.367	.390	.413	.436	.459
Weight, box, 14 x 20, lb.	65	70	75	80	85	90	95	100

Trade term	IC	IXL	IX	IXX	IXXX	IXXXX	IXXXXX
Nearest wire gauge No.	30	28	28	27	26	25	24
Weight, square foot, lb.	.491	.588	.619	.712	.803	895	.987
Weight, box, 14 x 20, lb.	107	128	135	155	175	195	215

	IC 14 x 20	IC 20 x 28	IX 14 x 20	IX 20 x 28
Black plates before coating weight per 112 sheets	lb. 95 to 100	lb. 190 to 200	lb. 125 to 130	lb. 250 to 260
When coated the plates weigh per 112 sheets	115 to 120	230 to 240	145 to 150	290 to 300

OTHER FORMS OF METAL ROOFING

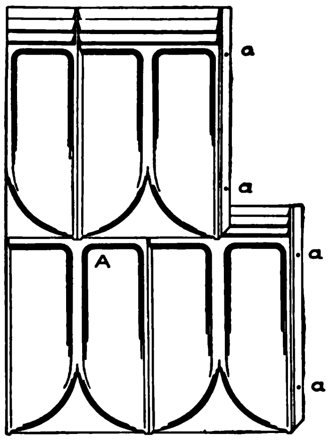


Fig. 189.

There is another form of roofing known as metal slates and shingles, pressed in various geometrical designs with water-tight lock attachments so that no solder is required in laying the roof. Fig. 189 shows the general shape of these metal shingles which are made from tin, galvanized iron, and copper, the dots *a a a a* representing the holes for nailing to the wood sheathing. In Fig. 190, A represents the side lock, showing the first operation in laying the metal slate or shingle on a roof, *a* representing the nail. B, in the same figure, shows the metal slate or shingle in position covering the nail *b*, the valley *c* of the bottom slate allowing the water, if any, to flow over the next lower slate as in A in Fig. 189.

In Fig. 191 is shown the bottom slate A covered by the top slate B, the ridges *a a a* keeping the water from backing up. Fig. 192 shows the style of roof on which these shingles are employed, that is, on steep roofs. Note the construction of the ridge roll, A and B in Fig. 192, which is first nailed in position at *a a* etc., after which the shingles B are slipped under the lock *c*. Fig. 193 shows a roll hip covering which is laid from the top downward, the lower end of the hip having a projection piece for nailing at *a*, over which the top end of the next piece is inserted, thus

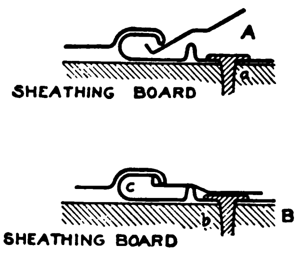


Fig. 190.

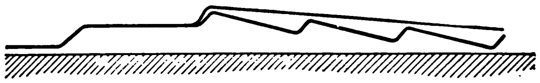


Fig. 191.

covering and concealing the nails. Fig. 194 represents a perspective view of a valley with metal slates, showing how the slates A are locked to the fold in the valley B. There are many other forms of metal shingles, but the shapes shown herewith are known as the Cortright patents.

TOOLS REQUIRED

Fig. 195 shows the various hand tools required by the metal roofer; starting at the left we have the soldering copper, mallet, scraper, stretch-awl, shears, hammer, and dividers. In addition to these hand tools a notching machine is required for cutting off the corners of the sheets, and roofing folders are required for edging the sheets in flat-seam roofing, and hand double seamer and roofing tongs for standing-seam roofing. The roofing double seamer and squeezing tongs can be used for standing-seam roofing (in place of the hand double seamer), which allow the operator to stand in an upright position if the roof is not too steep.

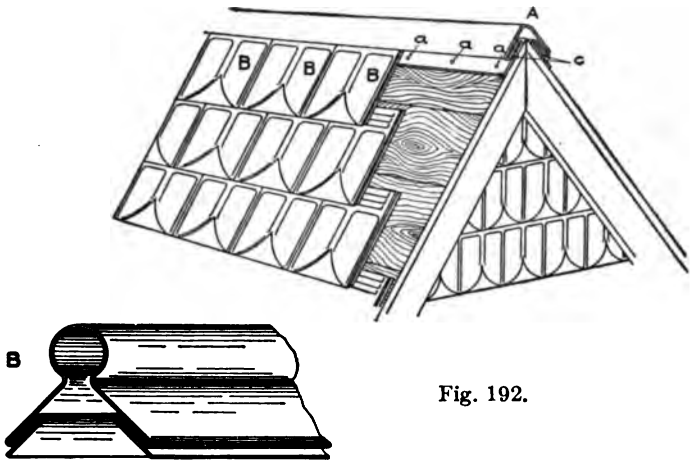


Fig. 192.

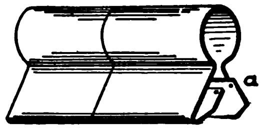


Fig. 193.

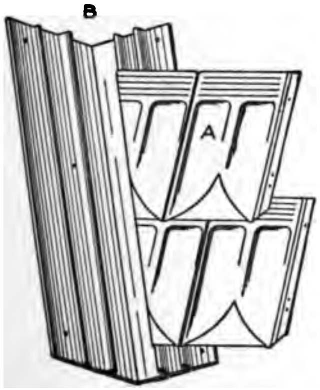


Fig. 194.

ROOF MENSURATION

While some mechanics understand thoroughly the methods of laying the various kinds of roofing, there are some, however, who do not understand how to figure from architects' or scale drawings the amount of material required to cover a given surface in a flat, irregular shaped, or hipped roof. The modern house with its gables and various intersecting roofs, forming hips and valleys, render it necessary to give a short chapter on roof measurement. In Figs. 196 to 198 inclusive are shown respectively the plans with full size measurements for a flat, irregular, and intersected hipped roof, showing how the length of the hips and valleys are obtained direct from the architects' scale drawings.

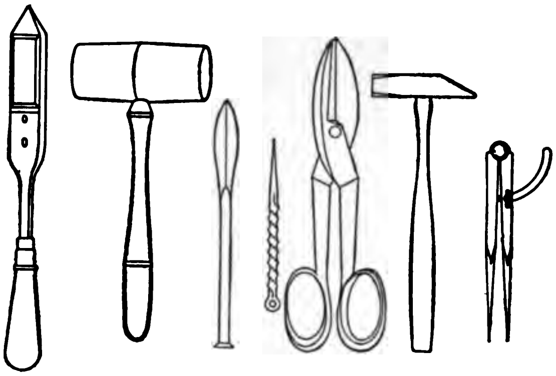


Fig. 195.

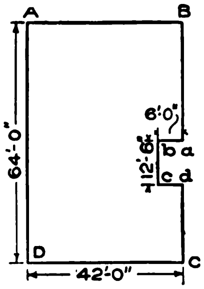


Fig. 196.

The illustrations shown herewith are not drawn to a scale as architects' drawings will be, but the measurements on the diagrams are assumed, which will clearly show the principles which must be applied when figuring from scale drawings. Assuming that the plans from which we are figuring are drawn to a quarter-inch scale, then when measurements are taken, every quarter inch represents one foot. $\frac{1}{8}$ inch = 6 inches, $\frac{1}{16}$ inch = 3 inches, etc. If the drawings were drawn to a half-inch scale, then $\frac{1}{2}$ inch = 12 inches, $\frac{1}{4}$ inch = 6 inches, $\frac{1}{8}$ inch = 3 inches, $\frac{1}{16}$ inch = $1\frac{1}{2}$ inches, etc.

A B C D in Fig. 196 represents a flat roof with a shaft at one side as shown by *a b c d*. In a roof of this kind we will figure it as if there was no air shaft at all. Thus 64 feet × 42 feet = 2,688 square feet. The shaft is 12.5 × 6 feet = 75 square feet; then 2,688 feet − 75 feet =

2,613 square feet of roofing, to which must be added an allowance for the flashing turning up against and into the walls at the sides.

In Fig. 197 is shown a flat roof with a shaft at each side, one shaft being irregular, forming an irregular shaped roof. The rule for obtaining the area is similar to that used for Fig. 196 with the exception that the area of the irregular shaft *x x x x* in Fig. 197 is determined differently to that of the shaft *b c d e*. Thus A B C D = 108 feet × 45 feet = 4,860 square feet. Find the area of *b c d e* which is 9.25 × 39.5 = 365.375 or 365$\frac{3}{8}$ square feet. To find the area of the irregular shaft, bisect *xx* and *xx* and obtain *a a*, measure the length of *a a* which is 48 feet, and multiply by 9. Thus 48 × 9 = 412, and 412 + 365.375 = 777.375. The entire roof minus the shafts = 4,860 square feet − 777.375 = 4,082.625 square feet of surface in Fig. 197.

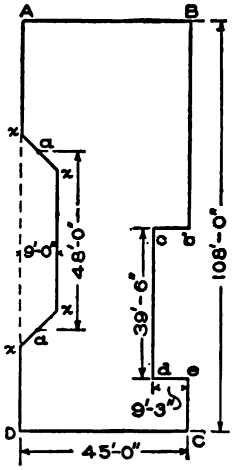


Fig. 197.

In Fig. 198 is shown the plan, front, and side elevations of an intersected hipped roof. A B C D represents the plan of the main building intersected by the wing E F G H. We will first figure the main roof as if there were no wing attached and then deduct the space taken

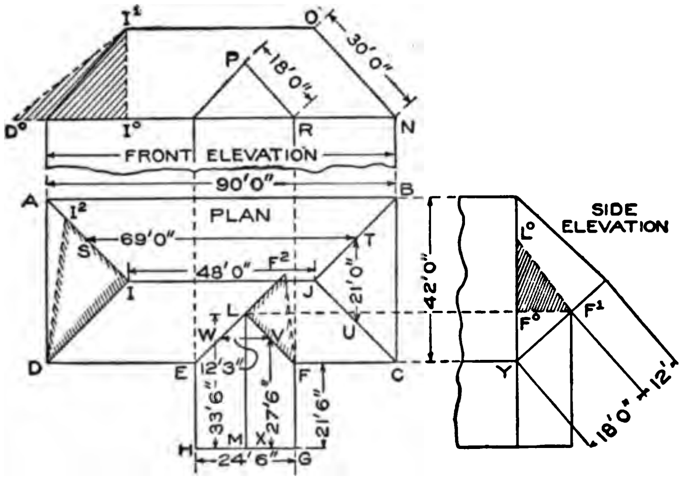
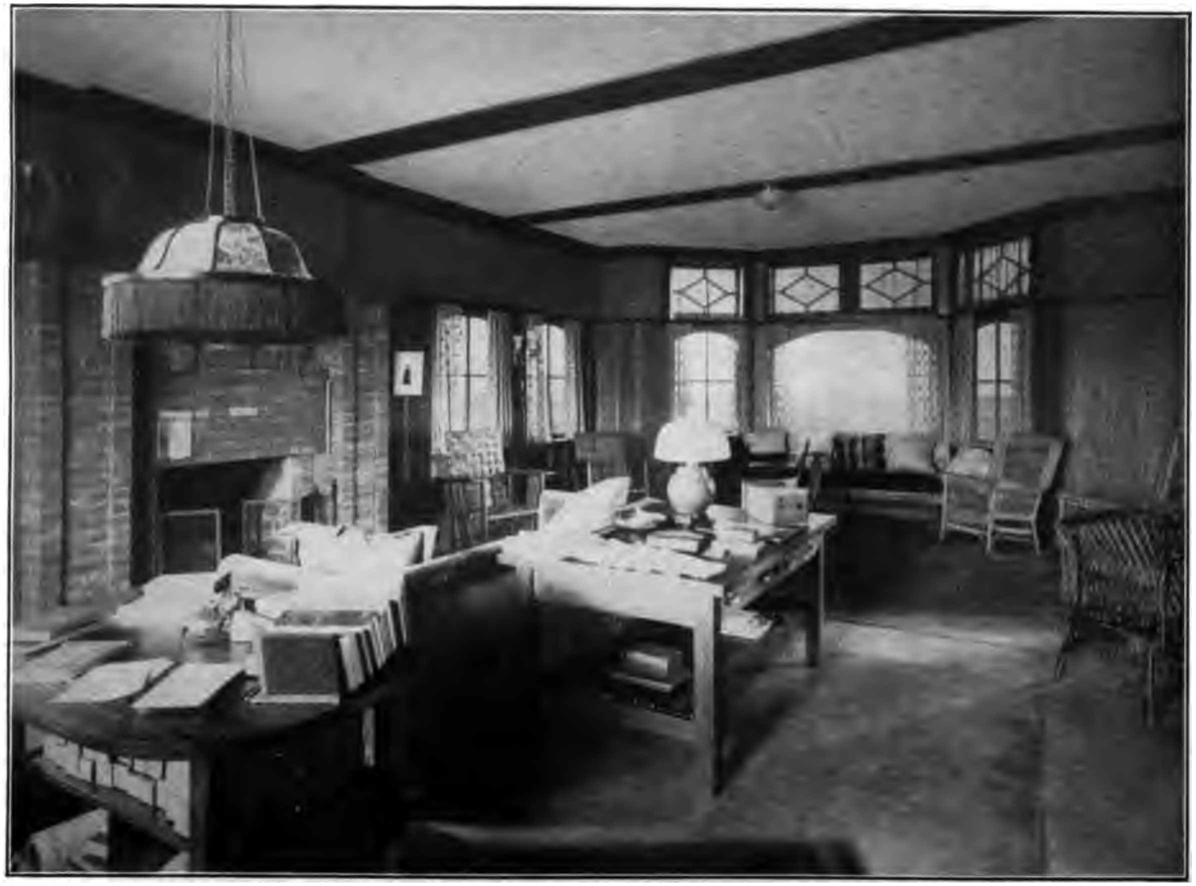


Fig. 198.

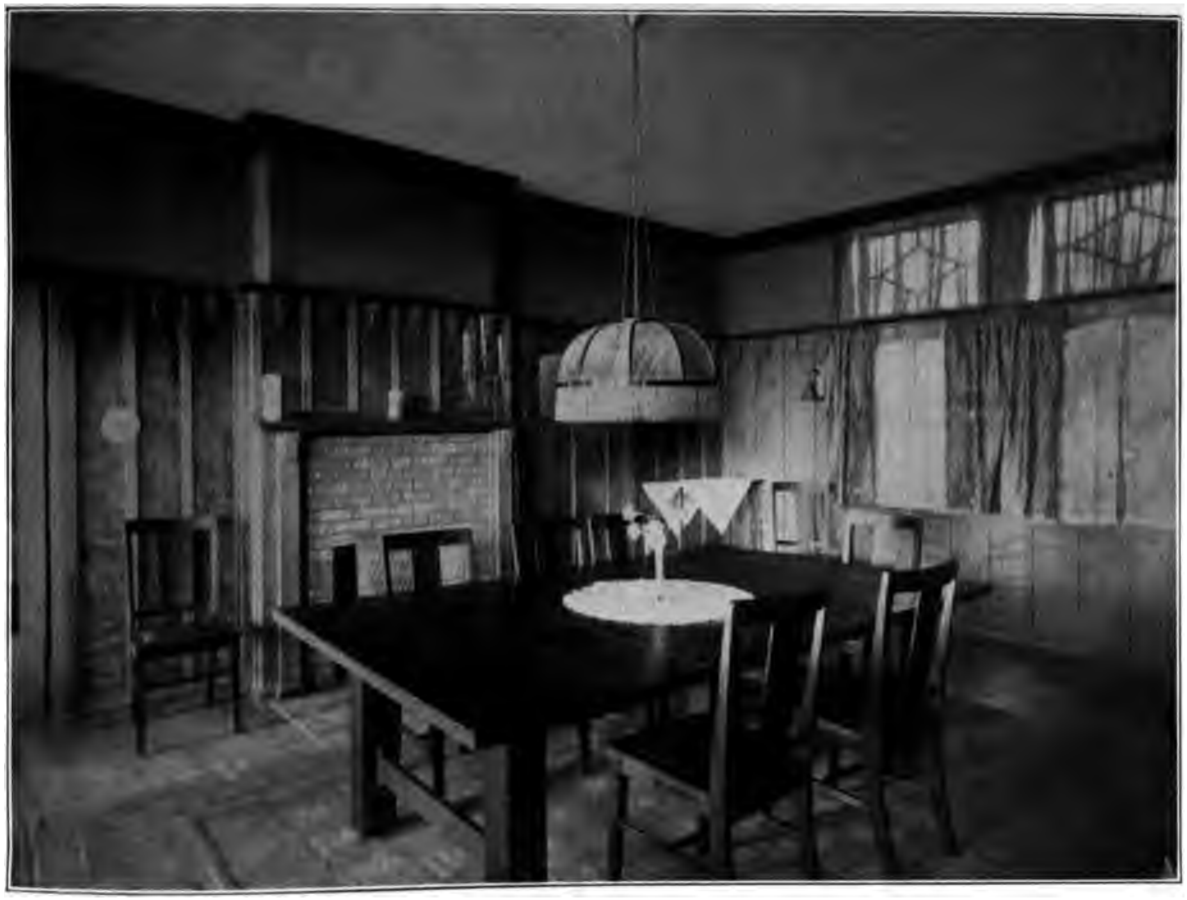
up by the intersection of the wing. While it may appear difficult to some to figure the quantities in a hipped roof, it is very simple, if the rule is understood. As the pitch of the roof is equal on four sides the length of the rafter shown from O to N in front elevation represents the true length of the pitch on each side. The length of the building at the eave is 90 feet and the length of the ridge 48 feet. Take 90 − 48 = 42, and 42 ÷ 2 = 21. Now either add 21 to the length of the edge or deduct 21 from the length of the eave, which gives 69 feet as shown from S to T. The length of the eave at the end is 42 feet and it runs to an apex at J. Then take 42 feet ÷ 2 = 21, as shown from T to U. If desired the hip lines A I, J B and J C can be bisected, obtaining respectively the points S, T, and U, which when measured will be of similar sizes; 69 feet and 21 feet. As the length of the rafter O N is 30 feet, then multiply as follows: 69 × 30 = 2070. 21 × 30 = 630. Then 630 + 2,070 = 2,700, and multiplying by 2 (for opposite sides) gives 5,400 square feet or 54 squares of roofing for the main building. From this amount deduct the intersection E L F in the plan as follows:

The width of the wing is 24 feet 6 inches and it intersects the main roof as shown at E L F. Bisect E L and L F and obtain points W and V, which when measured will be 12 feet 3 inches or one half of HG, 24 feet 6 inches. The wing intersects the main roof from Y to F^1 in the side elevation, a distance of 18 feet. Then take 18 × 12.25 = 220.5. Deduct 220.5 from 5400 = 5,179.5. The wing measures 33 feet 6 inches at the ridge L M, and 21 feet 6 inches at the eave F G, thus making the distance from V to X = 27 feet 6 inches. The length of the rafter of the wing is shown in front elevation by P R, and is 18 feet. Then 18 × 27.5 = 495, and multiplying by 2 (for opposite side), gives 995 sq. ft. in the wing. We then have a roofing area of 5,179.5 square feet in the main roof and 995 square feet in the wing, making a total of 6,174.5 square feet in the plan shown in Fig. 198.

If it is desired to know the quantity of ridge, hips, and valleys in the roof, the following method is used. The ridge can be taken from the plans by adding 48′ + 33′6″ = 81′ − 6″. For the true length of the hip I D in the plan, drop a vertical line from I^1 in the front elevation until it intersects the eave line 1°. On the eave line extended, place the distance I D in the plan as shown from 1° to D° and draw a line from D° to I^1 which will be the true length of the hip I D in the plan. Multiply this length by 4, which will give the amount of ridge capping re-



LIVING ROOM IN HOUSE FOR W. F. DUMMER AT CORONADO BEACH, CALIFORNIA
Pond and Pond, Architects, Chicago, Illinois
[illegible] wainscoting; fireplace, hard-burned variegated brick. For dining room see opposite page.



DINING ROOM IN HOUSE FOR MR. W. F. DUMMER AT CORONADO BEACH, CAL.
Pond & Pond, Architects, Chicago, Ill.
Curly California Redwood Wainscoting.

quired. This length of hip can also be obtained from the plan by taking the vertical height of the roof $I^\circ I'$ in the elevation and placing it at right angles to I D in the plan, as shown, from I to I^2, and draw a line from I^2 to D which is the desired length.

For the length of the valley L F in the plan, drop a vertical line from F^1 in the side elevation until it intersects the eave line at F°. Take the distance F L in the plan and place it as shown from F° to L°, and draw a line from L° to F^1, which is the true length of the valley shown by L F in the plan. Multiply this length by 2, which will give the required number of feet of valley required. This length of valley can also be obtained from the plan by taking the vertical height of the roof of the wing, shown by $F^\circ F^1$ in the side elevation, and placing it at right angles to F L in the plan, from L to F^2, and draw a line from F^2 to F which is the desired length similar to $F^1 L^\circ$ in the side elevation.

FLAT-SEAM ROOFING

The first step necessary in preparing the plates for flat seam roofing is to notch or cut off the four corners of the plate as shown in Fig. 199 which shows the plate as it is taken from the box, the shaded corners *a a a a* representing the corners which are notched on the notching machine or with the shears. Care must be taken when cutting off these corners not to cut off too little otherwise the sheets will not edge well, and not to cut off too much, otherwise a hole will show at the corners when the sheets are laid. To find the correct amount to be cut off proceed as follows:

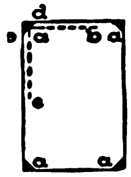


Fig. 199.

Assuming that a ½-inch edge is desired, set the dividers at ½ inch and scribe the lines *b a* and *a c* on the sheet shown in Fig. 199, and, where the lines intersect at *a*, draw the line *d e* at an angle of 45 degrees, which represents the true amount and true angle to be cut off on each corner. After all the sheets have been notched, they are edged as shown in Fig. 200, the long sides of the sheet being bent right and left, as shown at *a*, while the short side is bent as shown at *b*, making the notched corner appear as at *e*. In some cases after the sheets are edged the contract requires that the sheets be painted on the underside before laying. This is usually done with a small brush, being careful that the edges of the sheets

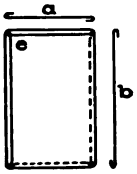


Fig. 200.

are not soiled with paint, which would interfere with soldering. Before laying the sheets the roof boards are sometimes covered with an oil or rosin-sized paper to prevent the moisture or fumes from below from rusting the tin on the underside. As before mentioned, the same method used for laying tin roofing would be applicable for laying copper roofing, with the exception that the copper sheets would have to be tinned about 1½ inches around the edges of the sheets after they are notched, and before they are edged.

In Fig. 201 is shown how a tin roof is started and the sheets laid when a gutter is used at the eaves with a fire wall at the side. A represents a galvanized iron gutter with a portion of it lapping on the roof, with a lock at C. In hanging the gutter it is flashed against the fire wall at J; after which the base flashing D D is put in position, flashing out on the roof at E, with a lock at F. Where the base flashing E miters with the flange of the gutter B it is joined as shown at *b*, allowing the flange E of the base flashing as shown by the dotted line *a*. As the water discharges at G, the sheets are laid in the direction of the arrow H, placing the nails at least 6 inches apart, always starting to nail at the butt *e e*, etc. Care should be taken when nailing that the nail heads are well covered by the edges, as shown in W, by *a*. Over the base flashing D D J the cap flashing L is placed, allowing it to go into the wall as at O.

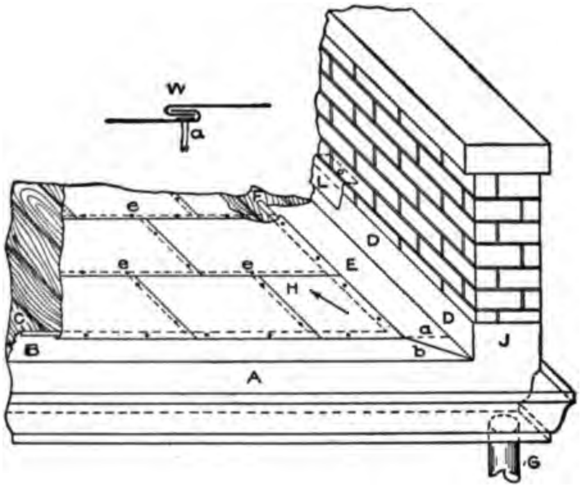


Fig. 201.

When putting in base flashings there are two methods employed. In Fig. 202 is shown a side flashing between the roof and parapet wall. A shows the flashing turning out on the roof at B, with a lock C, attached and flashed into the wall four courses of brick above the roof line, as shown at D, where wall hooks and paintskins or roofer's cement are used to make a tight joint. Flashings of this kind should always be painted on the underside, and paper should be placed between the brick work and metal, because the moisture in the wall is apt to rust the tin. This method of putting in flashing is not advisable in new work, because when the building is new, the walls and beams are liable to settle and when this occurs the flange D tears out of the wall, and the result is disagreeable leaks that stain the walls. When a new roof is to be placed on an old building where the walls and copings are in place and the brick work and beams have settled, there is not so much danger of leakage.

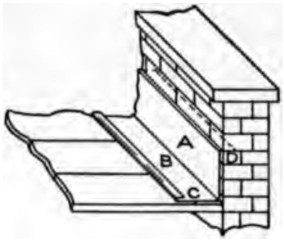


Fig. 202.

The proper method of putting in flashings and one which allows for the expansion and contraction of the metal and the settlement of the building is shown in Fig. 203, in which A shows the cap flashings, painted with two coats of paint before using. When the mason has built his wall up to four courses of brick above the roof line the cap flashing A is placed in position and the wall and coping finished; the base flashing B is then slipped under the cap A. In practice the cap flashing is cut 7 inches, then bent at right angles through the center, making each side *a* and *b* 3½ inches. The base flashing B is then slipped under the cap flashing A as shown at C.

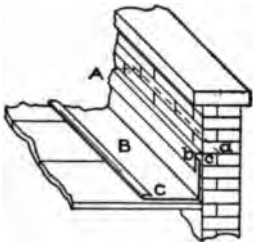


Fig. 203.

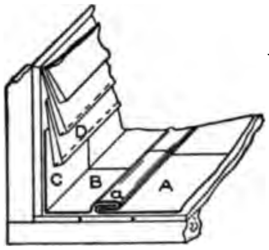


Fig. 204.

Where the cost is not considered and a good job is desired, it is better to use sheet lead cap flashings in place of tin. They last longer, do not rust, and can be dressed down well to lay tight onto the base flashings. Into the lock C the sheets are attached. After the sheets are laid the seams are flattened down well by means of a heavy mallet, with slightly convex faces, after which the roof is ready for soldering. When a base flashing is required on a roof which abuts against a wall composed of clap boards or shingles as shown in Fig. 204, then, after the last course of tin A has been laid, the flashing B with the lock *a* is locked into the course A and extends the required distance under the boards D. The flashing should always be painted and allowed to dry before it is placed in position. In the previous figures it was shown how the sheets are edged, both sides being edged right and left. In Fig. 205 is shown what is known as a valley sheet, where the short sides are edged both one way, as shown at *a a*, and the long sides right and left as shown at *b b*. Sheets of this kind are used when the water runs together from two directions as shown by A in Fig. 206. By having the locks *a* and *a* turned one way the roof is laid in both directions.

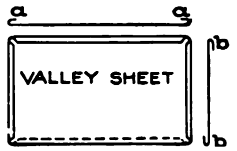


Fig. 205.

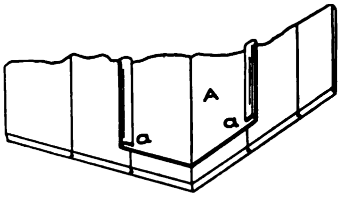


Fig. 206.

Fig. 207 shows a part plan of a roof and chimney A, around which the flashing B C D E is to be placed, and explains how the corners C and D are double seamed, whether on a chimney, bulkhead, or any other object on a roof when the water flows in the direction of the arrow F. The first operation is shown at *a* and the final operation at *b*. Thus it will be seen that the water flows past the seam and not against it. In laying flat seam roofing especially when copper is used, allowance must be made for the expansion and contraction of the sheets.

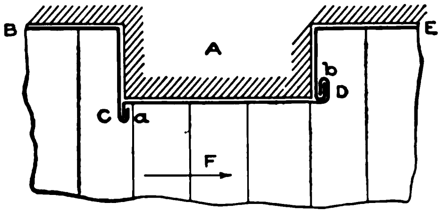


Fig. 207.

Care should be taken not to nail directly through the sheet as is shown in W, Fig. 201. While this method is generally employed in tin roofing, on a good job, as well as on copper roofing, cleats as shown at D in Fig. 208 should be used.

To show how they are used, A and B represent two locked-edged sheets. The lock on the cleat D is locked into the edge of the sheets and nailed into the roof boards at *a b c* and *d*, ar as often as required.

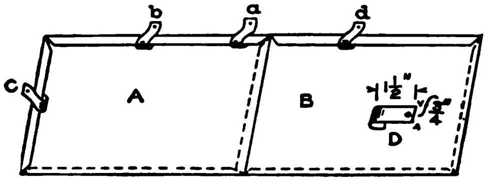


Fig. 208.

In this manner the entire roof can be fastened with cleats without having a nail driven into the sheets, thereby allowing for expansion and contraction of the metal. The closer these cleats are placed, the firmer the roof will be and the better the seams will hold. By using fewer cleats, time may be saved in laying the roof, but double this time is lost when soldering the seams, for the heat of the soldering copper will raise the seams, causing a succession of buckles, which retard soldering and require 10 per cent more solder. When the seams are nailed or cleated close it lays flat and smooth and the soldering is done with ease and less solder.

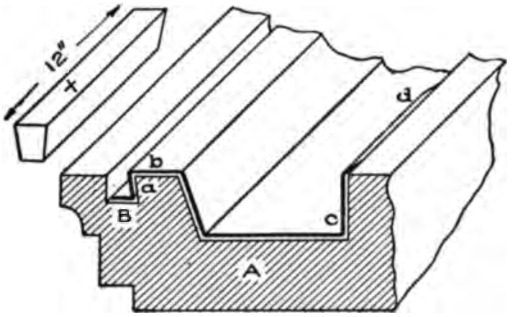


Fig. 209.

When a connection is to be made between metal and stone or terra cotta, the method shown in Fig. 209 is employed. This illustration shows a stone or terra-cotta cornice A. The heavy line ***a b c d*** represents the gutter lining, which is usually made from 20-oz. cold-rolled copper. If the cornice A is of stone, the stone cutter cuts a raggle into the top of the cornice A as at B, dove-tail in shape, after which the lining *a b c d* is put in position as shown. Then, being careful that there is no water or moisture in the raggle B, molten lead is poured into the raggle and after it is cooled it is dressed down well with the caulking chisel and hammer.

By having the dove-tail cut, the lead is secured firmly in position, holding down the edge of the lining and making a tight joint. Should the cornice be of terra cotta this raggle is cut into the clay before it is baked in the ovens. This method of making connection between metal and stone is the same no matter whether a gutter or upright wall is to be flashed. When a flashing between a stone wall and roof is to be made tight, then instead of using molten lead, cakes of lead are cast in molds made for this purpose, about 12 inches long, and these are driven into the raggle B as shown in Fig. 209 at X.

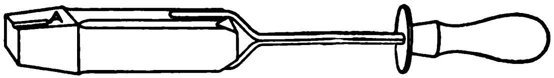


Fig. 210.

The most important step in roofing is the soldering. The style of soldering copper employed is shown in Fig. 210 and weighs at least 8 pounds to the pair. When rosin is used as a flux, it is also employed in tinning the coppers, but when acid is used as a flux for soldering zinc or galvanized iron, salammoniac is used for tinning the coppers. It will be noticed that the soldering coppers are forged square at the ends, and have a groove filed in one side as shown at A. When the copper is turned upward the groove should be filed toward the lower side within ¼ inch from the corner, so that when the groove is placed upon the seam, as shown in Fig. 211, it acts as a guide to the copper as the latter is drawn along the seam. The groove *a* being in the position shown, the largest heated surface *b* rests directly on the seam, "soaking" it thoroughly with solder. As the heat draws the solder between the locks, about 6 pounds of ½ and ½ solder are required for 100 square feet of surface using 14 x 20-inch tin. The use of acid in soldering seams in a tin roof is to be avoided as acid coming in contact with the

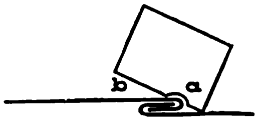


Fig. 211.

bare edges and corners, where the sheets are folded and seamed together, will cause rusting. No other soldering flux but good clean rosin should be employed. The same flux (rosin) should be used when soldering copper roofing whose edges have previously been tinned with rosin.

We will now consider the soldering of upright seams. The soldering copper to be employed for this purpose is shaped as shown in Fig. 212. It is forged to a wedge shape, about 1 inch wide and ¼ inch thick at the end, and is tinned on one side and the end only; if tinned otherwise, the solder, instead of remaining on the tinned side when soldering, would flow downward; by having the soldering copper tinned on one side only, the remaining sides are black and do not tend to draw the solder downward. The soldering copper being thus prepared, the upright seam, shown in Fig. 213, where the sheet B overlaps the sheet A 1", is soldered by first tacking the seam to make it lay close, then thoroughly soaking the seam, and then placing ridges of solder across it to strengthen the same. In using the soldering copper it should be held in the position shown by C, which allows the solder to flow forward and into the seam, while if the copper were held as shown by D, the solder would flow backward and away from the seam. In "soaking" the seam with solder the copper should be placed directly over the lapped part, so that the metal gets thoroughly heated and draws the solder between the joint. It makes no difference where this cross joint occurs; the same methods are used.

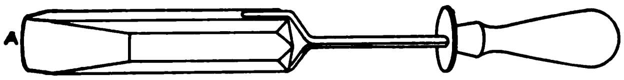


Fig. 212.

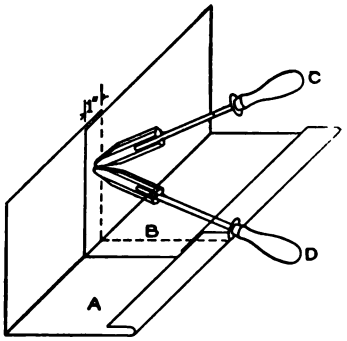


Fig. 213.

The roof being completed, the rosin is scraped off the seams and the roof cleaned and painted with good iron oxide and linseed oil paint. Some roofers omit the scraping of rosin and paint directly over it. This is the cause of rusting of seams which sometimes occurs. If the paint is applied to the rosin, the latter, with time, will crack, and the rain will soak under the cracked rosin to the tin surface. Even when the surface of the roof is dry, by raising the cracked rosin, moisture will often be found underneath, which naturally tends to rust the plate more and more with each storm. If the rosin is removed, the entire tin surface is protected by paint.

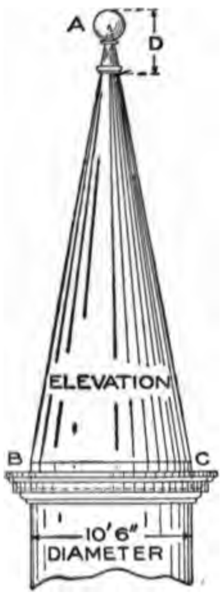


Fig. 214.

One of the most difficult jobs in flat-seams roofing is that of covering a conical tower. As the roof in question is round in plan and tapering in elevation, it is necessary to know the method of cutting the various patterns for the sheets. In Fig. 214 A B C shows the elevation of a tower to be covered with flat seam roofing, using 10 × 14-inch tin at the base. Assuming that the tower through B C is 10 feet 6 inches, or 126 inches, in diameter, the circumference is obtained by multiplying 126 by 3.1416 which equals 395.8416, or say 396 inches. As 10 x 14-inch plate is to be used at the base of the tower the nearest width which can be employed, and which will divide the space into equal spaces, is 13⅕ inches without edges, thus dividing the circumference in 30 equal spaces. This width of 13⅕ inches together with the length of the rafter A B or B C in elevation, will be the basis from which all the patterns for the various courses will be laid off.

At any convenient place in the shop or at the building, stretch a piece of tar felting of the required length, tacking it at the four corners with nails to keep the paper from moving. Upon the center of the felting strike a chalk line as A B in Fig. 215, making it equal to the length of the rafter A B or A C in Fig. 214. At right angles to A B in Fig. 215 at either side, draw the lines B D and B C each equal to 6⅗ inches, being one half of the 13⅕ above referred to. From the points C and D draw lines to the apex A (shown broken). As the width of the sheet used is 10 inches and as we assume an edge of ⅜ inch for each side, thus leaving 9¼ inches, measure on the vertical line A B lengths of 9¼ inches in succession, until the apex A is reached, leaving the last sheet at the top to come as it may. Through the points thus obtained on A B draw lines parallel to C D intersecting the lines A C and A D as shown. Then the various shapes marked 1 2 3 etc. will be the net patterns for similarly numbered courses. Take the shears and cut out the patterns on the felting and number them as required.

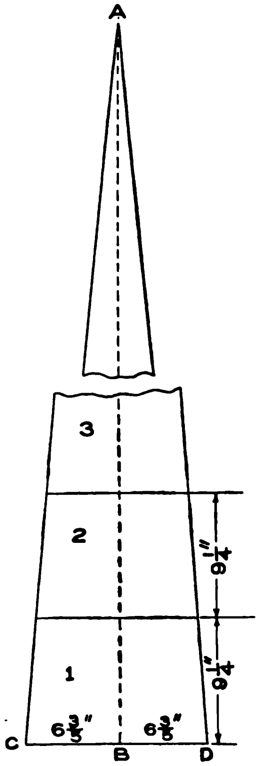


Fig. 215.

For example, take the paper pattern No. 1, place it on a sheet of tin as shown in Fig. 216, and allow ⅜-inch edges all around, and notch the corners A B C and D. Mark on the tin pattern "No. 1, 29 more", as 30 sheets are required to go around the tower, and cut 29 more for course No. 1. Treat all of the paper patterns from No. 1 to the apex in similar manner. Of course where the patterns become smaller in size at the top, the waste from other patterns can be used.

In Fig. 217 is shown how the sheets should be edged, always being careful to have the narrow side towards the top with the edge toward the outside, the same as in flat seam roofing. Lay the sheets in the usual manner, breaking joints as in general practice. As the seams are not soldered care must be taken to lock the edges well. After the entire roof is laid and before closing the seams with the mallet take a small brush and paint the locks with thick white lead, then close with the mallet. This will make a water-tight job. After the roof is completed the finial D in Fig. 214 is put in position.

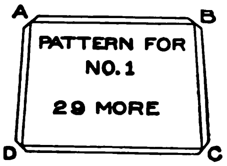


Fig. 216.

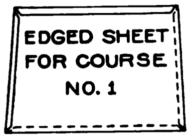


Fig. 217.

As the method used fcr obtaining the patterns for the various sheets in Fig. 215 is based upon the principle used in obtaining the envelope of a right cone, some student may say that in accurate patterns the line from C to D and all following lines should be curved, as if struck with a radius from the center A, and not straight as shown. To those the writer would say that the curve would be so little on a small pattern, where the radius is so long, that a straight line answers the purpose just as well in all practical work; for it would amount to considerable labor to turn edges on the curved cut of the sheet, and there is certainly no necessity for it.

When different metals are to be connected together, as for instance tin roofing to copper flashing, or copper tubes to galvanized iron gutters, or zinc flashings in connection with copper linings, care must be taken to have the copper sheets thoroughly tinned on both sides where it joins to the galvanized iron, zinc, or other metal, to avoid any electrolysis between the two metals. It is a fact not well known to roofers that if we take a glass jar and fill it with water and place it in separately, two clean strips, one of zinc and the other of copper, and connect the two with a thin copper wire, an electrical action is the result, and if the connection remains for a long time (as the action is very faint) the zinc would be destroyed, because, it may be said, the zinc furnishes the fuel for the electrical action, the same as wood furnishes the fuel for the fire. Therefore, if the copper was not tinned, before locking into the other metal, and the joint became wet with rain, the coating of the metal would be destroyed by the electrical action between the two metals, and the iron would rust through.

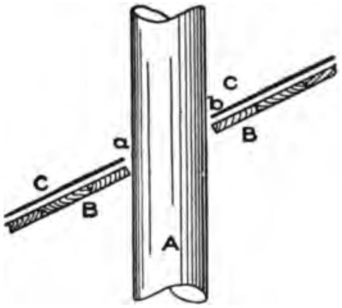


Fig. 218.

While the roofer is seldom called upon to lay out patterns for any roofing work occasion may arise that a roof flashing is required around a pipe passing through a roof of any pitch, as shown in Fig. 218, in which A represents a smoke or vent pipe passing through the roof B B, the metal roof flashing being indicated by C C. If the roof B B were level the opening to be cut into the flashing C C would simply be a true circle the same diameter as the pipe A. But where the roof pitches the opening in the flashing becomes an ellipse, whose minor axis is the same as the diameter of the pipe, and whose major axis is equal to the pitch *a b*. In Fig. 219 is shown how this opening is obtained by the use of a few nails, a string, and a pencil, which the roofer will always have handy.

First draw the line A B representing the slant of the roof, and then make the pipe of the desired size passing through this line at its proper angle to the roof line. Next draw the center line R S of the pipe, as shown. Call the point where this line intersects the roof line, I, and the points where D E and C F intersect A B, G and H respectively. Through I draw K L at right angles to A B, making K I and I L each equal to the half diameter of the pipe. Having established the minor axis K L and the major axis G H, the ellipse is made by taking I H, or half the major axis, as a radius, and with L as a center strike arcs intersecting the major axis, at points M and N. Drive a small nail in each of these two points and attach a string to the nails as shown by the dotted lines K M N, in such a way that when a pencil point is placed in the string it will reach K. Move the pencil along the string, keeping it taut all the time until the ellipse K H L G is obtained. Note how the position of the string changes when it reaches *a*, then *b*, etc.

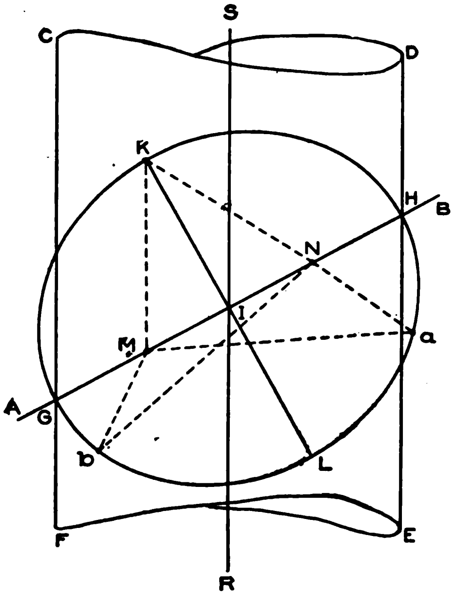


Fig. 219.

STANDING-SEAM ROOFING

Another form of metal roofing is that known as standing seam, which is used on steep roofs not less than $\frac{1}{6}$ pitch, or $\frac{1}{6}$ the width of the building. It consists of metal sheets whose cross or horizontal seams are locked as in flat seam roofing, and whose vertical seams are standing locked seams, as will be described in connection with Figs.

220 to 229 inclusive. Assume that 14 x 20-inch sheets are used and the sheets are edged on the 20-inch sides only, as shown by A in Fig. 220, making the sheet 13 x 20 inches. After the required number of sheets have been edged, and assuming that the length of the pitched roof is 30 feet, then as many sheets are locked together as will be required, and the seams are closed with the mallet and soldered. In practice these strips are prepared of the required length in the shop, painted on the underside, and when dry are rolled up and sent to the building. If desired they can be laid out at the building, which avoids the buckling caused by rolling and transportation from the shop to the job.

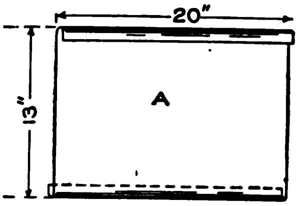


Fig. 220.

After the necessary strips have been prepared they are bent up with the roofing tongs, or, what is better and quicker, the roofing edger for standing-seam roofing. This is a machine into which the strips of tin are fed, being discharged in the required bent form shown at A or B in Fig. 221, bent up 1 inch on one side and 1¼ inches on the other side. Or the machine will, if desired, bend up 1½ inches and 1½ inches, giving a ¾-inch finished doubled seam in the first case and a 1-inch seam in the second. When laying standing-seam roofing, in no case should any nails be driven into the sheets. This applies to tin, copper or galvanized iron sheets. A cleat should be used, as shown in Fig. 222, which also shows the full size for laying the sheets given in Fig. 221. Thus it will be seen in Fig. 222 that ¼ inch has been added over the measurements in Fig. 221, thus allowing edges.

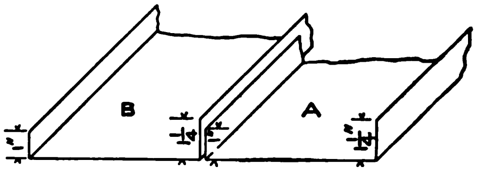


Fig. 221.

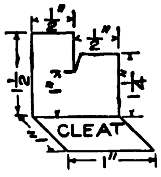


Fig. 222.

These cleats shown in Fig. 222 are made from scrap metal; they allow for the expansion and contraction of the roofing and are used in practice as shown in Fig. 223, which represents the first operation in laying a standing-seam roof, and in which A represents the gutter with a lock attached at B. The gutter being fastened in position by means of cleats under the lock B—the same as in flat seam roofing—the standing seam strips are laid as follows: Take the strip C and lock it well into the lock B of the gutter A as shown, and place the cleat shown in Fig. 222 tightly against the upright bend of the strip C in Fig. 223 as shown at D, and fasten it to the roof by means of a 1-inch roofing nail *a*.

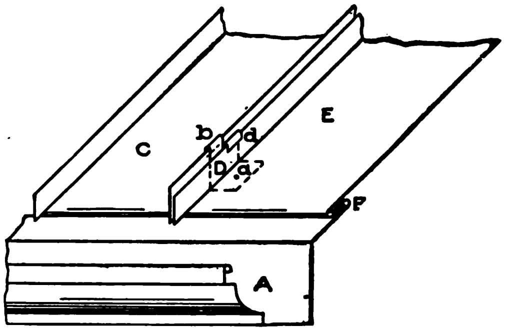


Fig. 223.

Press the strip C firmly onto the roof and turn over edge *b* of the cleat D. This holds the sheet C in position. Now take the next sheet E, press it down and against the cleat D and turn over the edge *d*, which holds E in position. These cleats should be placed about 18 inches apart and by using them it will be seen that no nails have been driven through the sheets, the entire roof being held in position by means of the cleats only.

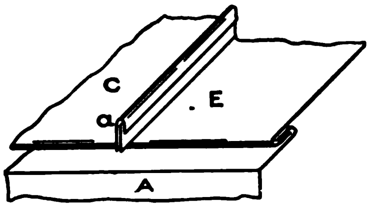


Fig. 224.

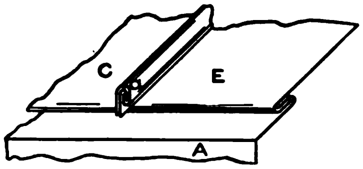


Fig. 225.

The second operation is shown in Fig. 224. By means of the hand double seamer and mallet or with the roofing double seamers and squeezing tongs, the single seam is made as shown at *a*. The third and last operation is shown in Fig. 225 where by the use of the same tools the doubled seam *a* is obtained. In Fig. 226 is shown how the finish is made with a comb ridge at the top. The sheets A A A have on the one side the single edge as shown, while the opposite side B has a double edge turned over as shown at *a*. Then, standing seams *b b b* are soldered down to *e*.

In Fig. 227 is shown how the side of a wall is flashed and counter flashed. A shows the gutter, B the leader or rain water conductor, and C the lock on the gutter A, fastened to the roof boards by cleats as shown at D. The back of the gutter is flashed up against the wall as high as shown by the dotted line E. F represents a standing-seam strip locked into the gutter at H and flashed up against the wall as high

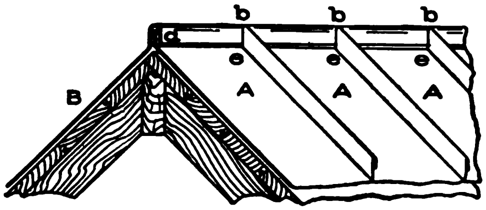


Fig. 226.

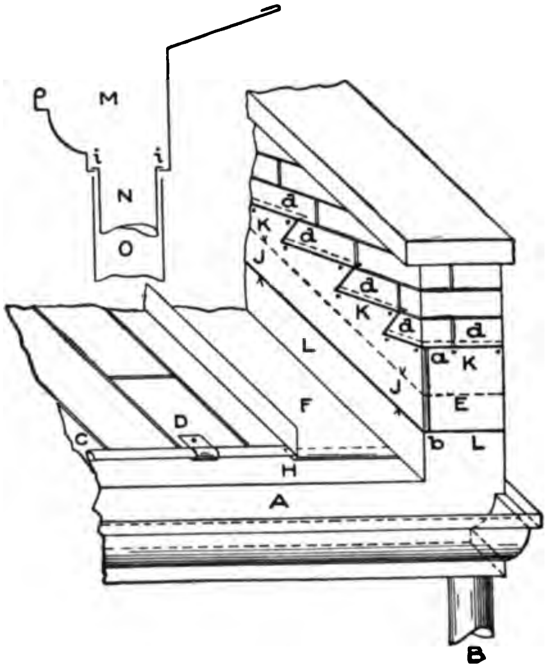


Fig. 227.

as shown by the dotted line J J. As the flashing J J E is not fastened at any part to the wall the beams or wall can settle without disturbing the flashing. The counter or cap flashing K K K is now stepped as shown by the heavy lines, the joints of the brick work being cut out to allow a one-inch flange *d d d* etc. to enter. This is well fastened with flashing hooks, as indicated by the small dots, and then made water-tight with roofer's cement. As will be seen the cap flashing overlaps the base flashing a distance indicated by J J and covers to L L; the corner is double seamed at *a b*. M shows a sectional view through the gutter showing how the tubes and leaders are joined. The tube N is flanged out as shown at *i i*, and soldered to the gutter; the leader O is then slipped over the tube N as shown, and fastened.

In the section on Flat-Seam Roofing it was explained how a conical tower, Fig. 214, would be covered. It will be shown now how this tower would be covered with standing-seam roofing. As the circumference of the tower at the base is 396 inches, and assuming that 14 x 20-inch tin plate is to be used at the base of the tower, the nearest width which can be employed and which will divide the base into equal spaces is 17 $\frac{5}{23}$ inches, without edges, thus dividing the circumference into 23 equal parts. Then the width of 17$\frac{5}{23}$ inches and the length of the rafter A B or A C in elevation will be the basis from which to construct the pattern for the standing seam strip, for which proceed as follows:

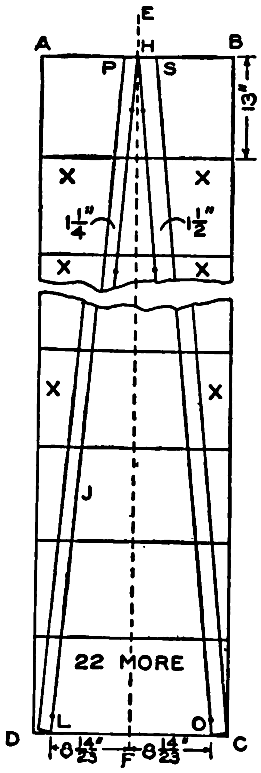


Fig. 228.

Let A B C D in Fig. 228 represent a 20-inch wide strip locked and soldered to the required length. Through the center of the strip draw the line E F. Now measure the length of the rafter A B or A C in Fig. 214 and place it on the line E F in Fig. 228 as shown from H to F. At right angles to H F on either side draw F O and F L making each equal to 8$\frac{14}{23}$ inches, being one half of the 17$\frac{5}{23}$ above referred to.

From points L and O draw lines to the apex H (shown broken). At right angles to H L and H O draw lines H P equal to 1¼ inches and H S equal to 1½ inches respectively. In similar manner draw L D and O C and connect by lines the points P D and S C. Then will P S C D be the pattern for the standing seam strip, of which 22 more will be required. When the strips are all cut out, use the roofing tongs and bend up the sides, after which they are laid on the tower, fastened with cleats, and double seamed with the hand seamer and mallet in the usual manner.

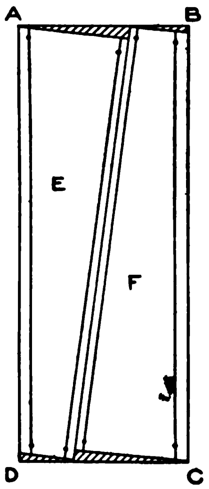


Fig. 229.

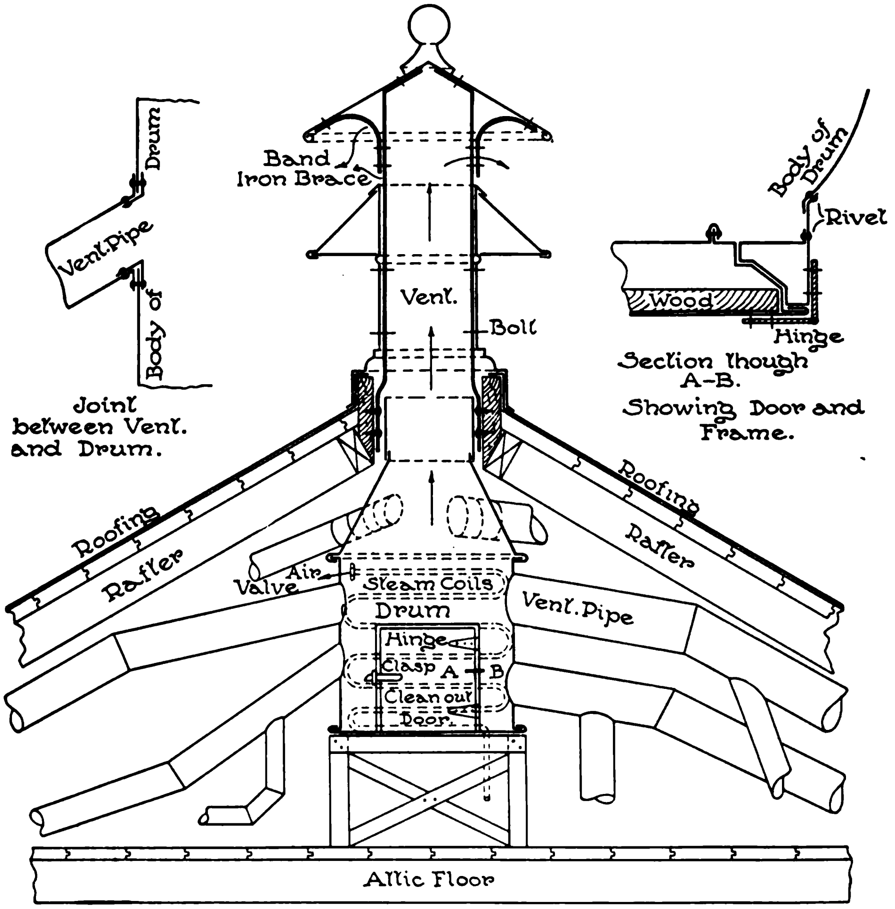
If the tower was done in copper or galvanized sheet iron or steel, where 8-foot sheets could be used, as many sheets would be cross-locked together as required; then metal could be saved, and waste avoided, by cutting the sheets as shown in Fig. 229 in which A B C D shows the sheets of metal locked together, and E and F the pattern sheets, the only waste being that shown by the shaded portion. Where the finial D in Fig. 214 sets over the tower, the standing seams are turned over flat as much as is required to receive the finial, or small notches would be cut into the base of the finial, to allow it to slip over the standing seams. Before closing the seams, they are painted with white lead with a tool brush, then closed up tight, which makes a good tight job.

CORRUGATED IRON ROOFING AND SIDING

Corrugated iron is used for roofs and sides of buildings. It is usually laid directly upon the purlins in roofs constructed as shown in Figs. 230 and 231, the former being constructed to receive sidings of corrugated iron, while in the latter figure the side walls of the building are brick. Special care must be taken that the projecting edges of the corrugated iron at the eaves and gable ends of the roof are well secured, otherwise the wind will loosen the sheets and fold them up. The corrugations are made of various sizes such as 5-inch, 2½-inch, 1¼-inch and ¾-inch, the measurements always being from A to B in Fig. 232, and the depth being shown by C. The smaller corrugations give a

CONSTRUCTION DRAWING SHOWING

SHEET METAL DRUM AND VENTILATOR IN VENTILATION WORK



Sectional view showing ventilation pipes connected to drum in attic also steam coils in drum to create suction.

more pleasing appearance, but the larger corrugations are stiffer and will span a greater distance, thereby permitting the purlins to be further apart.

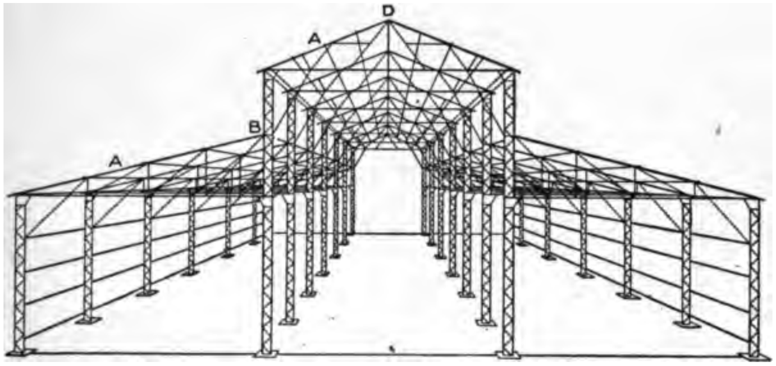


Fig. 230.

The thickness of the metal generally used for roofing and siding varies from No. 24 to No. 16 gauge. By actual trial made by The

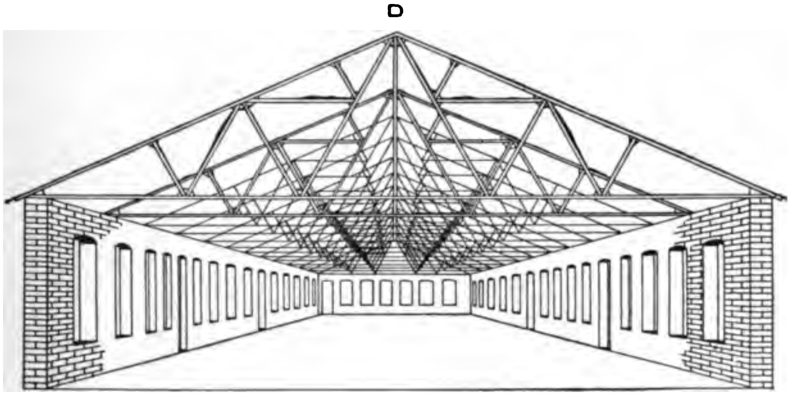


Fig. 231.

Keystone Bridge Company it was found that corrugated iron No. 20, spanning 6 feet, began to give permanent deflection at a load of 30 lb. per square foot, and that it collapsed with a load of 60 lb. per square foot. The distance between centers of purlins should, therefore, not exceed 6 feet, and preferably be less than this.

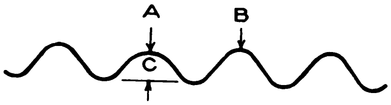


Fig. 232.

TABLES

The following tables will prove of value when desiring any information to which they appertain.

MEASUREMENTS OF CORRUGATED SHEETS

Dimensions of Sheets and Corrugations.

Kind of corrugation	Width of corrugation	Depth of corrugation	No. of corrugations to the sheet	Covering width after lapping one corrugation	Width of sheet after corrugated	Length of the longest sheets furnished
5 inch.	5 inch.	1 inch.	6	24 inch.	27 inch.	10 feet.
2½ inch.	2½ inch.	½ to ⅝ inch.	10	24 inch.	26 inch.	10 feet.
1¼ inch.	1¼ inch.	⅜ to ½ inch.	19½	24 inch.	26 inch.	10 feet.
¾ inch.	¾ inch.	¼ inch.	34½	25 inch.	26 inch.	8 feet.

RESULTS OF TEST

of a corrugated sheet No. 20, 2 feet wide, 6 feet long between supports, loaded uniformly with fire clay.

Load per square foot. lb.	Deflection at center under load. Inches.	Permanent Deflection, load removed.
5	½	0
10	¾	0
15	1	0
20	1¼	0
25	1½	0
30	1⅞	⅛
35	2¼	⅜
40	2⅝	¾
45	3½	1⅛
50	4	1½
55	6½	Not noted.
60	Broke down.	" "

The following table shows the distance apart the supports should be for different gauges of corrugated sheets:

Nos. 16 and 18	6 to 7 feet apart.
Nos. 20 and 22	4 to 5 feet apart.
No. 24	2 to 4 feet apart.
No. 28	2 feet apart.

The following table is calculated for sheets 30½ inches wide before corrugating.

No. by Birmingham gauge	Thickness Inch	Weight per square ft., flat Lb.	Weight per square ft., corrugated Lb.	Weight per square of 100 square feet, when laid, allowing 6 inches lap in length and 2½ inches or one corrugation in width of sheet, for sheet lengths of:						Weight per square ft., flat, galvanized Lb.
				5 feet	6 feet	7 feet	8 feet	9 feet	10 feet	
16	.065	2.61	3.28	365	358	353	350	348	346	2.95
18	.049	1.97	2.48	275	270	267	264	263	261	2.31
20	.035	1.40	1.76	196	192	190	188	186	185	1.74
22	.028	1.12	1.41	156	154	152	150	149	148	1.46
24	.022	.88	1.11	123	121	119	118	117	117	1.23
26	.018	.72	.91	101	99	97	97	96	95	1.06

LAYING CORRUGATED ROOFING

When laying corrugated iron on wood sheathing use galvanized iron nails and lead washers. The advantage in using lead washers is that they make a tight joint and prevent leaking and rusting at the nail hole; the washer being soft it easily shapes itself to any curve. In Fig. 233 is shown how these washers are used; A shows the full size nail and washer. When laying, commence at the left hand corner of the eave and end of the building. Continue laying to the ridge by lapping the second sheet over the first 4 inches, the left-hand edge being finished by means of a gable band A, formed as shown in Fig. 234, into which the corrugated sheet B is well bedded in roofer's cement C. When it is not desired to use this gable band the sheet must be well secured at the edge to keep the wind from raising the sheets from the roof in a storm, as at A in Fig. 230.

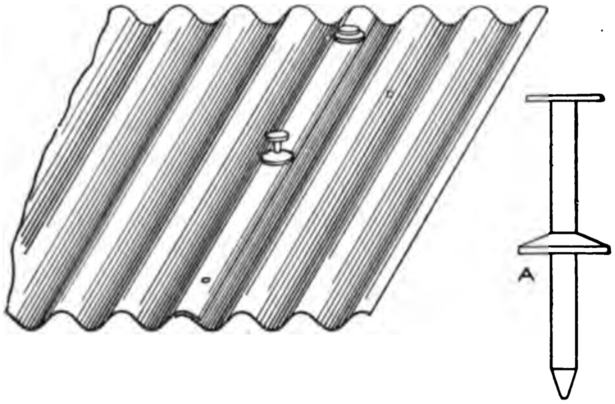


Fig. 233.

Should the gable have a fire wall, then let the sheets A butt against the wall and flash with corrugated flashing as shown in Fig. 235, over which the regular cap or counter flashing is placed as explained in connection with Fig. 227. Should the ridge of the roof A butt against a wall, as shown at B in Fig. 230, then an end-wall flashing is used as is shown in Fig. 236 which must also be capped, by either using cap flashing or allowing the corrugated siding to overlap this end-wall flashing as would be the case at B in Fig. 230. Now commence the second course at the eaves, giving one and one half corrugations for side lap, being careful that the side corrugations center each other exactly and nail with washers as shown in Fig. 237. Nail at every other corrugation at end laps, and at about every 6 inches at side laps, nailing through top of corrugation as shown in Fig. 237. Continue laying in this manner until the roof is covered.

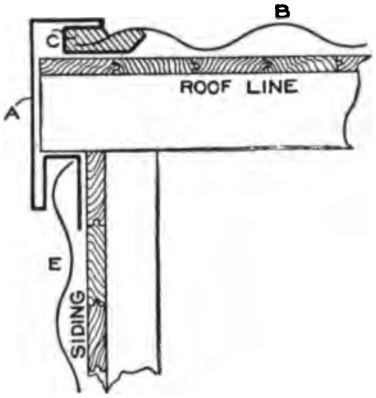


Fig. 234.

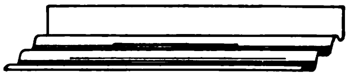


Fig. 235.

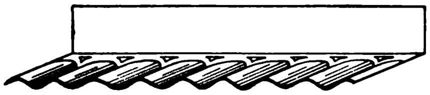


Fig. 236.

The same rule is to be observed in regard to laps and flashing if the corrugated iron were to be fastened to iron purlins, and the method of fastening to the iron frames would be accomplished as shown in Figs. 238 to 240 inclusive. Assuming that steel structures are to be covered, as shown in Figs. 230 and 231, then let A in Fig. 238 be the iron rafter, B the cross angles on which the sheets D are laid, then by means of the clip or clamp C, which is made from hoop iron and bent around the angle B, the sheets are riveted in position. In Fig. 239 is shown another form of clamp, which is bent over the bottom of the angle iron.

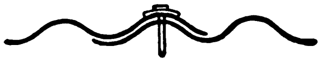


Fig. 237.

Fig. 240 shows still another method, where the clamp F is riveted to the sheet B at E, then turned around the angle A at D. To avoid having the storm drive in between the corrugated opening at the eaves, corrugated wood filler is used as shown in Fig. 241. This keeps out the snow and sleet. On iron framing this is made of pressed metal. Another form of corrugated iron roofing is shown in Fig. 242. This is put down with cleats in a manner similar to standing-seam roofing.

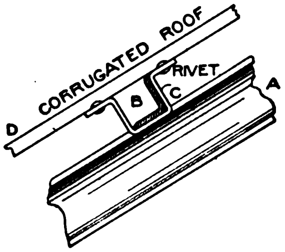


Fig. 238.

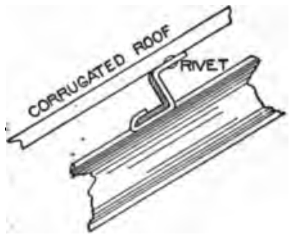


Fig. 239.

If there are hips on the roof, the corrugated iron should be carefully cut and the hip covered with sheet lead. This is best done by having a wooden cove or filler placed on the hip, against which the roofing butts. Sheet lead is then formed over this wooden core and into the corrugations, and fastened by means of wood screws through the lead cap into the wooden core. The lead being soft, it can be worked into any desired shape. When a valley occurs in a hipped roof, form from plain sheet iron a valley as shown in Fig. 243, being sure to give it two coats of paint before laying, and make it from 24-inch wide sheets, bending up 12 inches on each side. Fit it in the valley, and cut the corrugated iron to fit the required angle. Then lap the corrugated iron over the valley from 6 to 8 inches.

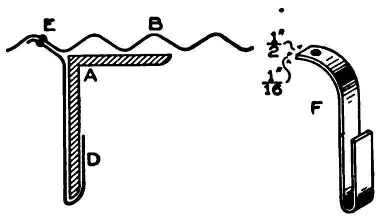


Fig. 240.

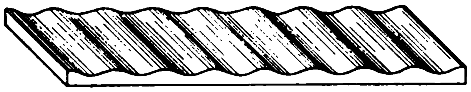


Fig. 241.

When a chimney is to be flashed, as shown in Fig. 244, use plain iron, bending up and flashing into the chimney joints, and allowing the flashing to turn up under the corrugated iron at the top about 12 inches and over the corrugated iron at the bottom about the same distance. At the side the flashing should have the shape of the corrugated iron and receive a lap of about 8 inches, the entire flashing being well bedded in roofer's cement. When a water-tight joint is required around a smoke stack, as shown in Fig. 245, the corrugated iron is first cut out as shown, then a flashing built around one half the upper part of the stack to keep the water from entering inside. This is best done by using heavy sheet lead and riveting it to the sheets, using strips of similar corrugated iron as a washer to avoid damaging the lead. Before riveting, the flashing must be well bedded in roofer's cement and then make a beveled angle of cement to make a good joint. After this upright flashing is in position a collar is set over the same and fastened to the stack by means of an iron ring bolted and made tight as shown. Cement is used to make a water-tight joint around the stack. This construction gives room for the stack to sway and allows the heat to escape.

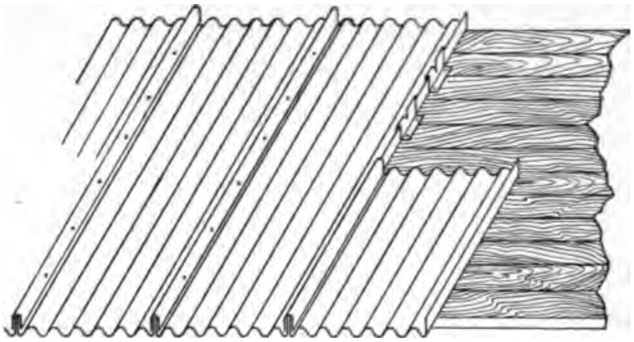


Fig. 242.

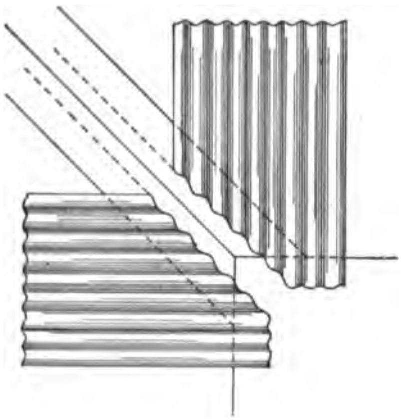


Fig. 243.

Sometimes the end wall flashing shown in Fig. 236 can be used to good advantage in building the upright flashing in Fig. 245. Where the corrugated iron meets at the ridge, as at D and D in Figs. 230 and 231, a wooden core is placed in position as explained in connection with the hip ridge, and an angle ridge, pressed by dealers who furnish the corrugated iron, is placed over the ridge as shown in Fig. 246. When a ridge roll is required, the shape shown in Fig. 247 is employed.

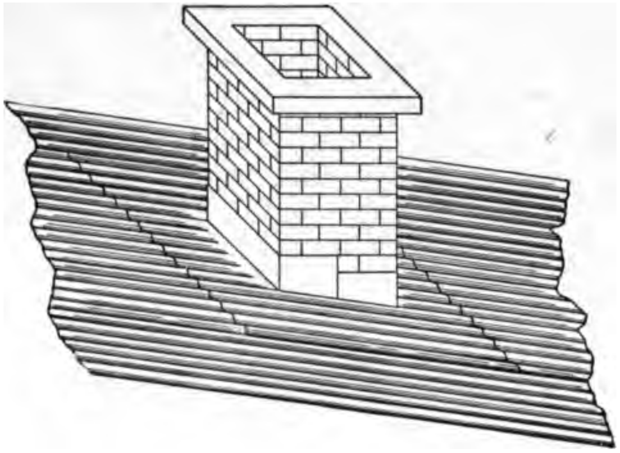


Fig. 244.

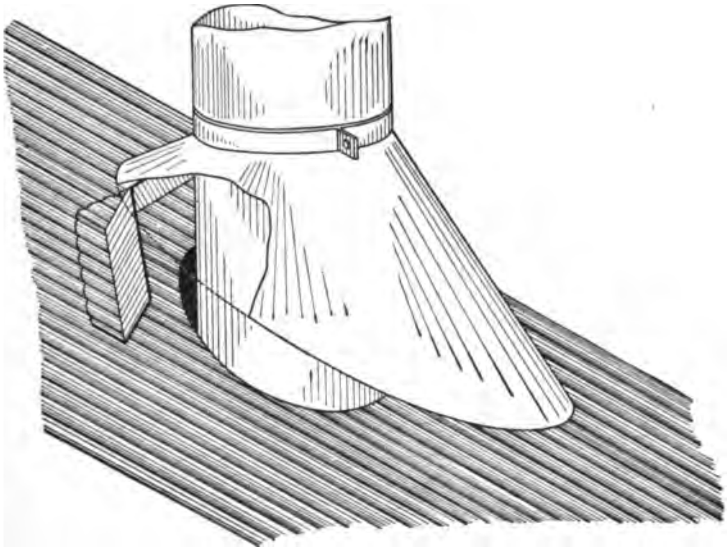


Fig. 245.

These ridges are fastened direct to the roof sheets by means of riveting or bolting.

LAYING CORRUGATED SIDING

Before putting on any corrugated siding or clapboarding, as shown in Fig. 248, a finish is usually made at the eaves by means of a hanging gutter or a plain cornice, shown in Fig. 249, which is fastened to the projecting wooden or iron rafters. This method is generally used on elevators, mills, factories, barns, etc., where corrugated iron, crimped iron or clapboards are used for either roofing or siding. This style of cornice covers the eaves and gable projections, so as to make the building entirely ironclad. When laying the siding commence at the left hand corner, laying the courses from base to cornice, giving the sheets a lap of two inches as the ends and one and one half corrugations at the sides. Nail side laps every 6 inches and end laps at every other corrugation, driving the nails as shown in Fig. 250.

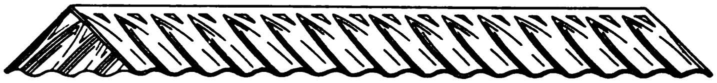


Fig. 246.

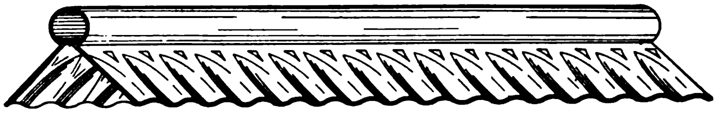


Fig. 247.

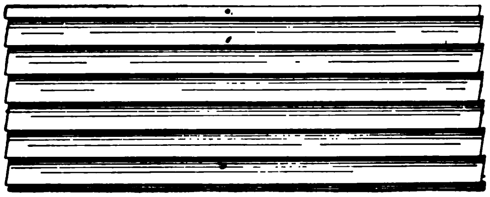


Fig. 248.

Where the sheets must be fastened to iron framing use the same method as explained in connection with Figs. 238, 239 and 240. In this case, instead of nailing the sheets, they would be riveted. If siding is put on the wooden studding care should be taken to space the studding the same distance apart as the laying width of the iron used. In this case pieces of studding should be placed between the uprights at the end of each sheet to nail the laps. When covering grain elevators it is necessary to use swinging scaffolds. Commence at the base and carry up the course to the eave, the length of the scaffold. Commence at the left hand and give the sheets a lap of one corrugation on the side and a two-inch lap at the end. Nail or rivet in every corrugation 3 inches from the lower end of the sheet; this allows for settling of the building.

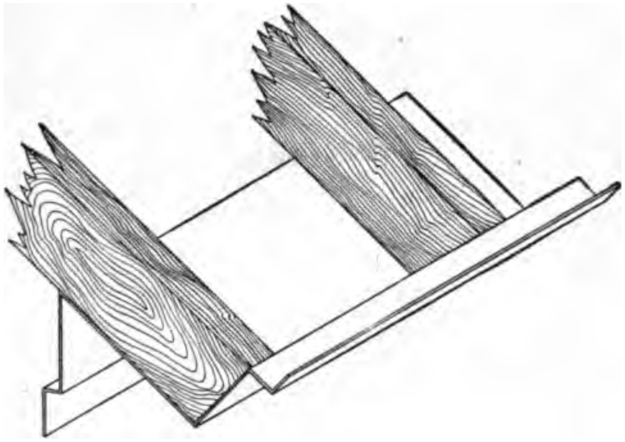


Fig. 249.

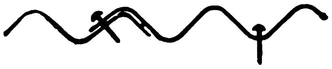


Fig. 250.

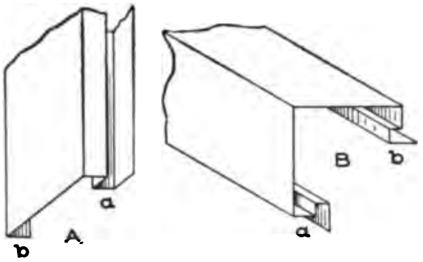


Fig. 251.

When any structure is to be covered on two or more sides, corner casings made of flat iron are employed, of a shape similar to that shown at B, Fig. 251. It will be seen that a rabbet is bent on both sides *a* and *b* to admit the siding. This makes a neat finish on the outside and hides the rough edges of the siding. If a window opening is to have casings a jamb is used as shown at A, Fig. 251, which has a similar rabbet at *a* to receive the siding, and a square bend at *b* to nail against the frame. In Fig. 252 is shown the cap of a window or opening. It is bent so that *a* is nailed to the window or other frame at the bottom, while *b* forms a flashing over which the siding will set. Fig. 253 shows the sill of a window, which has a rabbet at *a*, in which the siding is slipped; then *b* forms a drip, and any water coming over the sill passes over the siding without danger of leaks; *c* is nailed in white lead to the window frame.

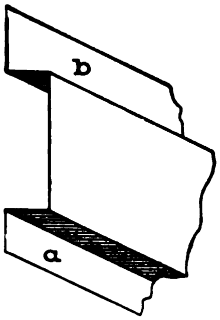


Fig. 252.

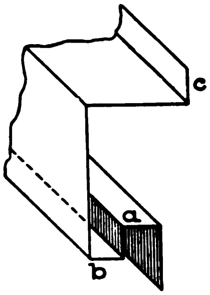


Fig. 253.

Another use to which corrugated iron is put is to cover sheds and awnings. Sheets laid on wood are nailed in the usual manner, while sheets laid on angle iron construction are fastened as explained in the preceding sections. In Fig. 254 is shown an awning over a store laid on angle iron supports. In work of this kind, to make a neat appearance, the sheets are curved to conform to the iron bracket A.

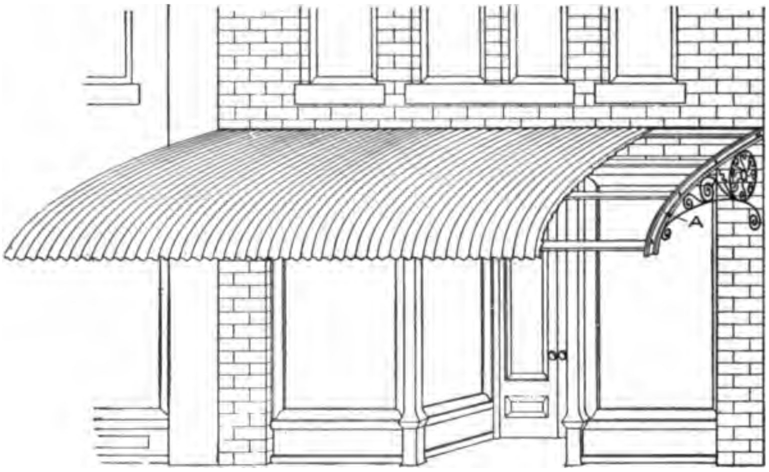
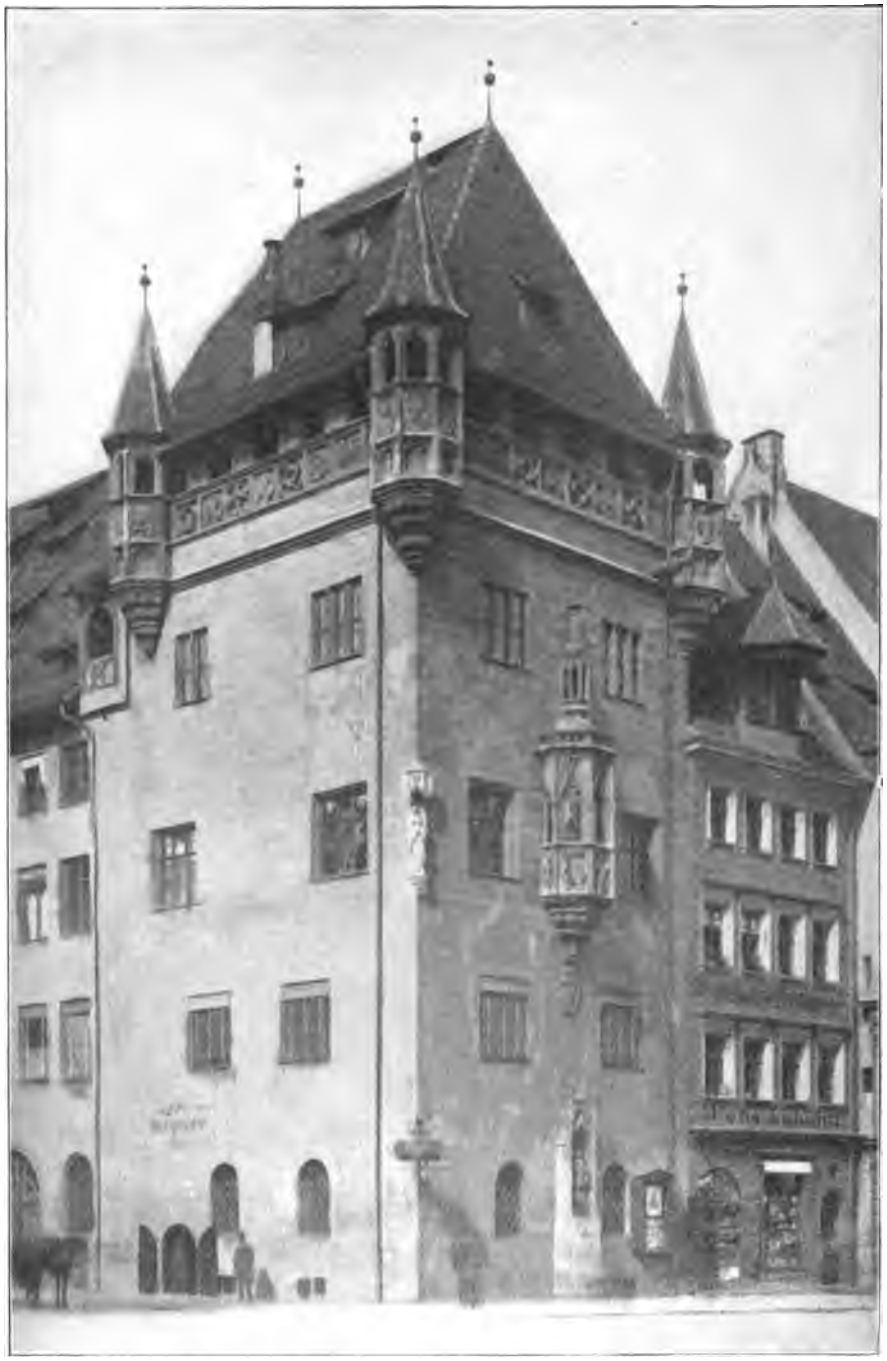


Fig. 254.



THE "NASSAUER HAUS" IN NÜRNBERG, GERMANY

Built at the End of the Thirteenth Century. Railing of Gallery underneath Red-Tiled Roof is Decorated with Coats of Arms. In the Niche over the Fountain at the Lower Right, is a Statue of King Adolf von Nassau.

PLASTERING

The subject of plastering in relation to modern dwellings is necessarily divided into two sections. The first treats of the plastering of walls on the *interior* of the house; the second will briefly describe some of the various ways of finishing in cement plaster the house *exterior*.

INTERIOR PLASTERING

The installation of interior plastering marks the division between the completion of the *rough work* on the residence, and the very beginning of the placing of the *finish* that is to follow.

The plastering cannot be started until the walls and ceilings have been lathed, and the ceilings must be furred before even the lathing can be begun. When the building is ready for lathing, all of the rough studding, framework, and partitions must be set in place; and the piping and wiring necessary in the plumbing, heating, lighting, etc., of the dwelling, must be installed and tested before the lathing or furring can be started.

The apparent break in the progress of building necessary to lath, plaster, and dry out a house, need not be altogether time lost for any of the various trades. Those unable to resume work until this intermediary process has been completed, can be securing their necessary materials and fixtures and arranging them ready for installation. The carpenter can be getting out his mill work and finish, be ready to put in his window-sash, set his standing finish in place around doors and windows, lay the upper floors, etc., and complete the remainder of his contract. The painter and paperer then commence their work; the electricians, plumbers, and heating contractors install their service fixtures, and the dwelling is soon ready for occupation.

The studs of a building are spaced sixteen inches apart on centers, so that each lath receives four nailings. Each end of the lath rests upon the center of a stud; and the two intermediate studs provide fastenings at spaces equally distant in its length. The ceilings are customarily furred to provide lath nailings, four—and in better work, five—nailings to the lath, with furrings seven-eighths of an inch thick and one and one-quarter inches or more wide, running crosswise of the floor joists. This furring is intended to level up the bottom of the joists, and distributes the unequal result of their shrinkage or uneven settlement from the weight above, thus preventing plaster cracks. Where the exterior walls are of masonry construction, they are generally furred by the carpenter with ⅞-inch strips set vertical and spaced 16-inch centers. This operation serves to true up the walls and to provide an air space to protect the plaster from exterior moisture.

Before beginning lathing, the carpenter should see that each partition, at its intersection with another wall, is started with a stud nailed directly against the crossing studding. This makes it impossible for the lather to run the ends of his laths in behind or over the partitions—a careless practice that provides a very unstable internal plaster angle. The carpenter also sets wood grounds, ¾-inch thick, around all window and door openings and around the walls back of base, picture moulding, etc., to provide nailings for the finish woodwork. As these grounds form lines for finished plaster surfaces, it is imperative that they be set straight and true. It is essential for the carpenter to place any necessary furring for cornices, door-caps, etc., before the lathing is begun; also any other furring blocks that may be required by the plumber to secure the setting of his fixtures or to support and carry his pipes.

LATHING

Wood Laths. Wood laths are put up in bundles of 100 laths; and are nailed upon the studdings of the wooden frame, with a space of one-quarter inch between them. This distance is sufficient to allow for lath shrinkage or swelling, and still provide a firm clinch for the plastering. If the space is much less than this, the plaster clinch will be weakened. If much more, the laths may possibly sag down on the ceilings with the extra weight of plaster. In no instance should these spaces between laths exceed a width of three-eighths of an inch.

The *clinch*, or *key*, of the plaster is formed by the mortar being pressed through the spaces between the laths and then spreading out back of the laths, so forming a tie, or clinch, that holds the mortar firmly and securely in place.

It occasionally becomes necessary to lath on very thin furrings to cover over a heating pipe, a brick or iron support, or some other such exceptional instance of construction. In that case a wider space between the laths may strengthen the plaster clinch; or, better still, wire lath and metal furring may be used over or around such obstructions.

The best wooden laths are made of white pine or spruce, and are only partially seasoned. They should be free from sap, bark, and dead knots. Both bark and knots are likely to loosen from the surrounding wood and so destroy the hold of the plaster; while the face of the plaster is occasionally stained from pitchy knotholes, bark, or sap. All laths are now machine-sawn. The old-fashioned split lath has not been in the market for more than fifty years.

If the laths are too dry, the wet mortar is likely to cause them to warp and twist; and if it hardens or sets before the laths become saturated, their swelling is likely to produce parallel plaster cracks. Better results can be obtained by using wet laths, when both mortar and laths dry out together.

In specifying the nailing of wood laths, it is sometimes thought to ensure better work if two nailings are required at each end of the lath, either upon the ceiling alone or upon both wall and ceiling. It is more than doubtful if this requirement produces the desired result, as two nails in the lath end are likely to start a split, which may be increased by the pressure necessary in applying the mortar, until the entire end of the lath is partially or whooly loosened from its support before the plastering is all upon the wall. Large lath nails, instead of making the work more secure, weaken it in the same way. The common-sized inch-and-one-eighth long—"three-penny fine"—nails fasten the laths securely, even the ceiling nails rarely pulling out. About five pounds of nails will be necessary to each one thousand laths.

The joints of laths are ordinarily broken every six courses. This means that not more than six adjoining lath ends are nailed upon one stud or furring, the next six laths, in both directions, being carried by, ending upon the next wall stud or on furring to either right or left, thus alternating the break and obviating the possibility of an extended crack occurring at the line of lath jointure. Occasionally studding is placed twelve inches apart, and the lath joints broken for every other lath. Such precautions, however, are not necessary in the ordinary dwelling. They increase expense; and the closer spacing of the studs, especially, provides more undesirable weight to be carried by the house frame.

Wherever the wood studding of partitions comes up against the brickwork of chimneys or a terra cotta or brick wall, strips of expanded metal or wire-mesh lath should be employed, extending seven or eight inches over upon either side of such a joint; and, if such a joint occurs in an internal angle, future cracking from a difference in settlement or shrinkage may be prevented by cutting through each plaster coat, when soft, with a sharp trowel.

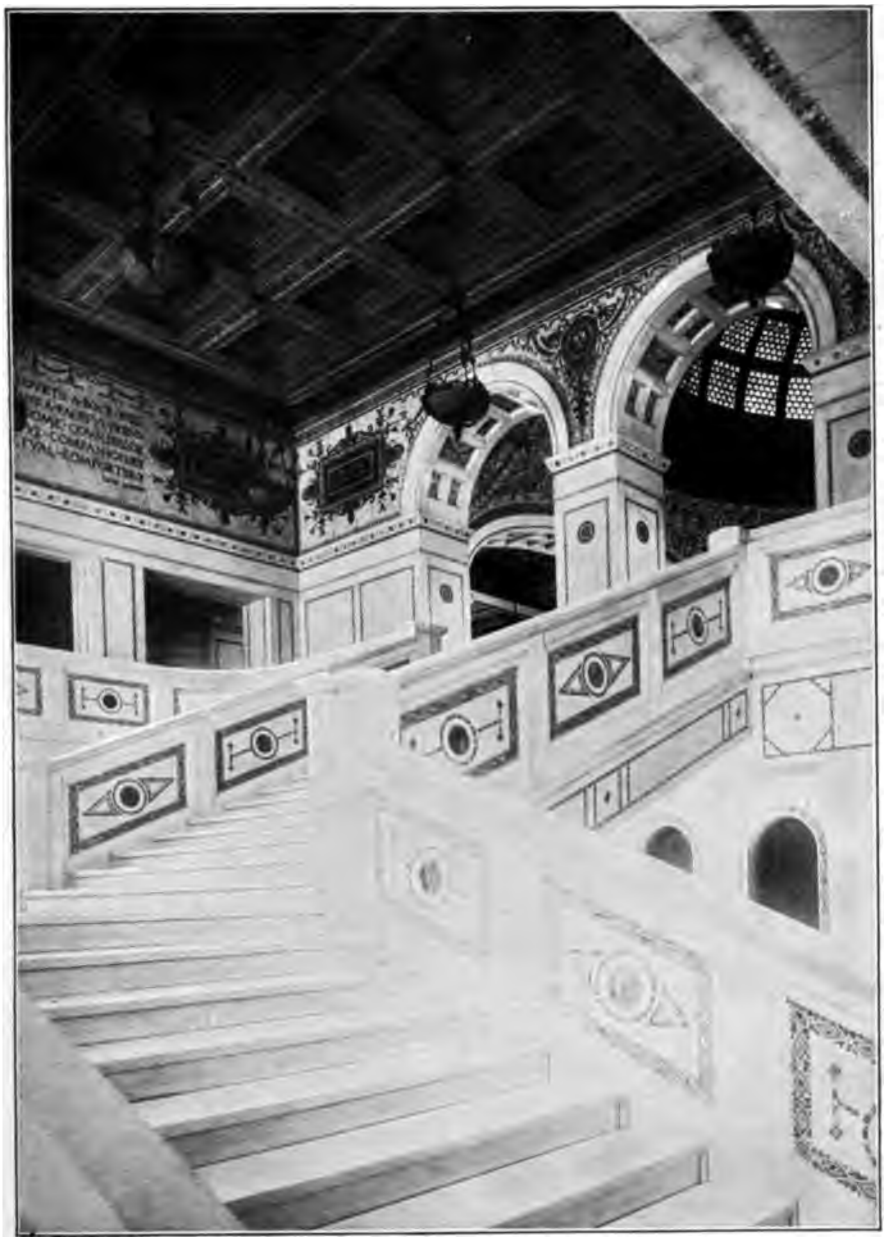
Metal Lath. Of late years many varieties of metal lath have been placed upon the market. The use of such lath is generally required on boiler-room ceilings, and in other places exposed to strong artificial heat. Many varieties of metal lath—including all those made of wire—require supports at closer intervals than is provided by the studding, 12 inches being generally considered the best distance. This necessitates either a closer spacing of studs than is otherwise necessary or desirable, or a series of furrings fastened to the wall studding.

There are some metal laths—generally those made on the expanded principle—that are sufficiently stiff, in one direction, to allow of a spacing of supports greater than 12 inches; but, for ordinary wire cloth, no wider distance should ever be allowed, unless the cloth is itself artificially stiffened. All metal lath should be securely fastened by staples, and stretched before nailing, to increase its stiffness as much as possible.

In using metal lath, care should be taken to prevent plaster cracks along the line of jointure. The use of metal lath also requires three coats of plaster, in order to stiffen the lath sufficiently to resist the pressure required to finish the last coat.

Lathing and plastering are generally estimated, and the various materials are all figured, by the square yard. In small work, no openings are deducted unless they exceed sixty square feet in area. In figuring up plaster by quantity, when openings are allowed for, it is sometimes customary to add half of the contents when measuring closets; while small triangular wall pieces are figured as though square, in order to make up for the extra amount of labor required in plastering such restricted or odd-sized surfaces.

The use of expanded metal or wire lath is frequently demanded



CHICAGO PUBLIC LIBRARY

Shepley, Rutan & Coolidge, Architects, Chicago, Ill.

Washington Street Staircase, Looking towards Delivery Room. Finished in 1897. Italian Statuary Marble, with Marble and Glass Mosaic Inlay; Ornamental Plaster Ceiling; Bronze Light-Fixtures.

by the building laws of some cities, and is always required on a fireproof or first-class building. It is essential that metal lath or expanded metal be galvanized or thoroughly coated with waterproof paint or compound to prevent rusting.

Several makes of *plaster board* are in the market and being extensively advertised. They come in eight inch wide boards or large sheets of 32 by 36 inches, and are nailed directly upon the wall framing. One coat of plaster—in three-coat work—may then be dispensed with. These boards save time, being rapidly set in place even by unskilled carpenters, and the plaster also dries out much more rapidly. They are, however, frequently the cause of cracks that appear in the finished plaster where the edges of the boards come together—sometimes even after the wall has been papered.

PLASTER MATERIALS

Plaster is principally composed of *lime, sand, hair,* and *water.*

Lime is obtained in different sections of the country from calcined limestone, the carbonic acid and moisture contained in the stone being driven off by the burning process. The whole theory of plastering is based upon the reduction of limestone to lime, and its chemical recombination, when distributed upon the walls of a house, into something approaching its original state. The *slaking* of the lime provides the moisture necessary for the process of crystallization that produces the *set* of the mortar; while the sole purpose of applying it upon the wall in several coats is to present that much more surface to absorb the carbonic acid—of which it was originally deprived in burning—from the air. The thinner the coats and the larger their total exposed surface, the greater the absorption of this strengthening constituent. For this reason—and solely for this reason—is three-coat plaster work to be considered as better than two.

Properly burnt lime slakes easily and completely, when water is added, and bubbles and hisses with the heat generated by the process. This is what is called the *slaking* of lime. Very rich and pure lime—the best for plastering—increases to about twice its original bulk by being slaked, and is then almost pure white in color. Lime should always be as fresh as possible, and must be delivered in tightly sealed barrels. Care should also be taken to ascertain that it has been burned with wood and not with coal.

Sand is broken rock which has become decomposed spontaneously or by the action of running water. That made by running water, or from stones worn small by rolling over and over upon the beach, is composed of particles so nearly round in contour and so lacking in angularities of surface that they are not good material for mixing in any mortar where *strength* is a requisite or necessity. The particles of rock decomposed by exposure are better adapted to make good sand for mixing with mortar, their shape being more irregular, with many sharp and angular corners. Sand obtained from ledge stones contains the essential elements of those stones, quartz, feldspar, and mica being present in granite formations, and lava, obsidian, etc., in volcanic sand. The sand coming from the softer stones is generally more thoroughly disintegrated, but is frequently so rotten as to be entirely unsuitable for use in plastering. In most parts of the country the principal supply of sand now comes from the beds of ancient lakes or rivers, and is called *pit sand.* True sand, no matter how fine, may always be distinguished from dust by dropping it into a glass of water, as it will invariably sink to the bottom without leaving any appreciable dirt upon the surface.

For plastering purposes, sharply angular sand is not absolutely essential. Good river sand, the coarser the better, is obtained so easily, and is so clean and free from dirt, clay, and earth stains, that it is most generally employed for plaster.

The third necessary constituent is *hair.* The best hair upon the market is cattle hair obtained from the tanneries. The hair should be of good length; and, if too lumpy or clotted, it should be separated by soaking in water the day before mixing it with the mortar, as this method of separating the hair is less dusty and more healthful than beating or whipping it dry to obtain the same result.

Occasionally brick dust is added to the mortar for coloring, when it is likely that the mortar will set more rapidly—especially if the dust is mixed in shortly before using and is dry at the time of mixing. All brick dust should be sifted through a fine sieve. Besides brick dust, a variety of colorings for mortar are used—such as lampblack, ivory black, powdered charcoal, Spanish brown, raw umber, burnt umber, red aniline, Venetian red, Indian red, vermilion, ultramarine blue, indigo blue, chrome yellow, and, occasionally, pulverized clay. Mineral colors should be preferred to earth colorings. The latter weaken the plaster, and fade rapidly. Variously colored sands —when they can be obtained—make the best and most durable materials possible for tinting the final plaster coat.

It is impossible to state arbitrary, set, hard-and-fast proportions for the mixing of plastering for either exterior or interior work. The different makes of lime and grades of sand, alone, vary sufficiently to make any such statements exceedingly inadvisable; while the purpose and conditions under which the plaster is to be used, frequently occasion considerable changes in its proportions.

"Working" the Lime. The first process in the making of plaster is the *slaking* of the lime. This consists, as already said, in simply reducing the hard, brittle lumps of its original form to a smooth paste by mixing it with water. It is of the utmost importance that the lime should be entirely and completely slaked, and the paste smoothly and evenly *worked*, before adding any of the other ingredients.

The lime is slaked in a *mortar-bed*, a box of boards about 4 feet wide and 7 feet long, and a foot to eighteen inches high, set in some convenient location with its bottom about level with the top of a second box placed at one end, and about two feet lower in grade. Both mortar and lime-slaking beds should have tight bottoms and strong sides, well braced to resist the pressure that will come upon them when they are full. A quantity of sand already screened should also be near at hand. Poorly screened sand later causes extra trouble and work. Gravel in the mortar delays workmen while plastering and floating, and much good plaster material will be lost in hurriedly throwing or picking out these gravel stones in the rush of applying the mortar on the wall.

The barrel lime is emptied into the upper box, and water is poured on while a workman breaks up the lumps and works the mass back and forth in various directions with a hoe. The thorough working of the material at this stage is necessary to ensure its complete slaking. The tendency of the careless workman is to hoe back and forth in the center of the bed without any regard as to whether he is stirring up the mortar that is down on the bottom boards, or whether the corners are drawn into the mixture and worked as evenly as the remainder of the box. If the paste is not thoroughly and evenly worked to an equal consistency throughout, if the water is not conducted to every particle of lime, or if the other ingredients are mixed in before the paste is evenly prepared, the lime will be apt to *blister* and slake out unevenly, causing trouble after it is upon the wall. If the corners, for instance, are imperfectly mixed, lumps of clear lime will afterward appear. Many of these lumps will pass unnoticed under the hoe of the workman tempering the mortar, and will not be found until they are flattened out under the wall trowel of the plasterer.

If too much water is used in slaking the lime—especially if a too great amount is added at once—the pile is *chilled* and forms into lumps that slake too tardily. If too little water is added, the lime is left so dry (*burns*, as the plasterers call it) that many small particles entirely fail to slake through lack of sufficient moisture. When too much water *drowns* the lime in the first place, it becomes so thoroughly chilled that a considerable portion of its strength is lost; and the process of slaking is, by the very excess of water, much retarded. The process is also slowed up if very cold water is added, although the water soon becomes heated from the reaction of the lime. At the start, just enough water should be put on to initiate the slaking process. After this, as the slaking proceeds, more water should be added as needed, taking care to keep the lime thoroughly moist at all times. A very active and quick slaking lime should be covered with water from the very beginning, to guard against the possibility of burning. If the lime once *burns*, it will afterward be impossible, by any amount of working, to get out all the fine lumps that are then caused. Rich lime will afterwards work cool, is little likely to crack, and bears troweling when being finished, without the surface peeling off, blistering, or staining.

If lumps of unslaked lime escape through the screen when the lime is run off, and get mixed into the mortar, it becomes very difficult to eradicate them afterward. It is not possible for the plasterer to get these lumps out of the mortar when working it on the wall; and the results of their afterwards slaking out will continue to appear long after the house is finished. If they occur in the first coat, at various times after the work is completed (frequently extending throughout the entire first year) these lime lumps will suddenly blow or expand, forcing out the surface plastering outside them and making a large blister or lump generally about an inch in diameter, which, if upon the ceiling, almost invariably falls off. If this unslaked lime gets into the final coat, much the same result occurs, although the particles are of necessity smaller in size. Instead of being large, the resulting holes are then comparatively small, running generally about the size of the head of a pin, and the entire surface of the plastering is frequently pitted, the particles thrown off appearing about the room in the shape of a white dust.

In the brown rough-coat, the spots of white, unslaked lime are quite easy to see, as they are often the size of a bean or pea. However, in the final white coat, these spots, being smaller and of the same color as the rest of the mortar, do not show.

After it has once begun to warm up, the lime should be worked or stirred thoroughly during the process of slaking, so that, after the action has been completed, it will be of the consistency of a pasty cream. After slaking, the lime should be run off through a fine sieve (No. 5 screen) put at the end of the slaking box, into the next lower compartment, or mortar-bed. The screen is intended to keep out any lime lumps too large to slake before the mortar is used, or any flinty settlement that may be found in the lime, and to allow only a pure and thoroughly mixed hydrate to be admitted to the bed.

When drawing or running off the lime, a large supply of sand already screened should be at hand to scatter in the bottom of the mortar-bed and to use for stopping leaks that may appear as the box gradually fills. This screened sand should be sufficient in amount to complete the mortar mixture. An ample supply of water, either in barrels or in hose piped from a hydrant, should also be ready at hand—to avoid any possibility of the lime burning.

For the *putty* or *finish coat*, the paste should be made even thinner before running off, and may be of the consistency of milk. The sieve through which it is strained should also be finer, of about the mesh of an ordinary flour or meal screen. The paste for this coat is often obtained by running off the lime a second time, as by this means a cooler working putty is secured.

The length of time that mortar for plastering should be mixed before being used, is a much-discussed question. It is generally stated in architectural specifications, that "the mortar should be mixed ten days or two weeks before using." As a matter of fact, this requirement is not always either wise or desirable. It is true that, in old English work, lime mortar was left covered over with earth to stand for long periods of time, often six months to three years elapsing before it was used. In this country, such slow-going methods are not to be expected. While lime does gain in strength by standing in this thin putty state before sand or other materials have been mixed with it, yet three or four weeks, at the least, are necessary before the increase becomes very apparent. It is also necessary that the paste should remain moist, by being kept covered all the time. At the end of the fourth month its strength will have increased about one-fifth, and most of this gain has been made during that month. From then on the gain continues, but gradually decreases in amount.

It is more economical for the plasterer to use a lime that has been slaked for some weeks, as, when tempered down, it will work freely with the admixture of a much larger proportion of sand than is taken up by lime mixed as soon as it can be readily worked. This extra amount of sand does not add to the strength of the mortar; but, as it causes the lime to cover a greater surface, it is a considerable economy for the contractor, made, however, at the expense of the quality of his work.

Lime mortar need be left standing only long enough for all its particles to be thoroughly slaked, and, if properly mixed and wet down in the first case, a great deal of time need not be required to effect that result. This once secured, the quicker the mortar is mixed and put upon the building, the better and stronger will be the plastering that is obtained. It is further claimed that the accompanying loss of limewater is also very harmful, as this water—from the properties which it has already absorbed from the lime—is much better suited for carrying on the process of mixing than newly added clean water. Yet, if the lime has been long standing, it may be necessary to add clean water to replace the water lost by evaporation or seepage, although mortar mixed with clean water never becomes so hard as that mixed with the water obtained in slaking the lime.

The sand and hair are next added, the hair being put in before the mortar becomes too stiff to work readily. After the sand is mixed, the mortar should not be left to stand for any length of time, as it would become considerably set and a loss of strength would result. If the mortar does become set in the bed, reworking would be necessary before it could be put upon the walls. The strength then lost bears a direct relation to the length of time it has stood, and the solidity it has attained, before this final working up.

In plastering mortar where hair is required, a still further loss of strength would result, as the hair would be so rotted or eaten by its long exposure to the action of the wet lime as to be almost or quite worthless. The hair cannot well be mixed evenly, except at the time when the mortar is first run off, while it is in a very thin paste. If, after a lime-and-sand mixture had been standing for some months, it were attempted to bring it to a sufficiently fluid state to receive the hair properly, by wetting it down a second time, a considerable proportion—varying from a quarter up to almost a half—of its strength would be sacrificed.

Bearing these facts in mind—once certain that the lime is slaked—it would appear better that not more than a week should elapse before the use of this mortar; and a less time than that is, under many circumstances, undoubtedly desirable. It is evident that no more lime-and-sand mortar should be mixed at one time than can be used within a few days at the most. The length of time that mortar should be allowed to stand, is determined more or less by the dryness or moisture of the atmosphere. The dryer the atmosphere, the shorter the time, as the setting of the mortar is, in part, a chemical result of the drying out, or evaporation, of the *water of crystallization*, as it is called.

It has already been said that limes made in different parts of the country vary extensively in their chemical composition and properties. A knowledge of the chemical composition of lime mortars and the individual peculiarities of the lime locally used, is necessary before applying or attempting to utilize the principles here set forth. In the eastern part of the United States, the limes frequently contain from a third to a half of carbonate of magnesia; and the mortar in which such limes are employed sets very readily.

To sum up, the lime should be slaked as evenly and thoroughly as possible. It should be run off from the slaking bed through a fine sieve into the mortar-bed It should lie there no longer than is absolutely necessary; and if it could be possible to add the hair and sand while the original mixture is sufficiently moist to take up and work the entire amount of the latter material to be added, the resulting mixture would undoubtedly be that much the stronger and more durable.

Mixing the Mortar. The amount of sand to be mixed in with the lime paste is a variable quantity, depending upon the sand itself, upon the quality and thickness of the lime paste, and also upon the nature of the work for which the mortar is intended. With exceptionally rich limes, sand to the amount of about two times the bulk of the lime—measuring the slaked lime in the form of a rather firm paste—may be added. As will be seen, this is a most uncertain proportion, for a great deal depends upon the firmness of the lime paste alone. Allowing for variation in size of the lumps of lime and their closer or looser packing together, it may perhaps be better to say that the sand should bear a relation to the lime, before it is slaked, of from three to four and one-half times its bulk.

The richer the lime and the finer the particles of sand, the more of the latter should be employed, although the finer sand does not make as hard or as good mortar as the coarser variety. If both are clean and sharp, the finer and coarser varieties of sand may be mixed together with good results. Most laborers are apt to stop adding sand, merely because the mortar mixture becomes hard to work when the paste becomes too thick. This is poor policy, inasmuch as the mixture becomes much harder to work when the tempering is partly completed, a day or two later.

The fineness of the sand is an important factor. A rather coarse as well as sharp sand is considered best, as the amount and capacity of the voids left in such a mixture would be of such size as, without any doubt, would provide space to contain lime sufficient to cement this granular mass very firmly together. The close pressure and contact of the sand particles would also lessen the possibility of settlement or shrinkage, with accompanying *map-cracks*. The hair may be mixed in either before the adding of the sand or when but a very small proportion of the latter has been worked into the lime mixture. The hair is generally mixed with the mortar by means of an iron rake. It should be thoroughly mixed, and enough should be used to make it impossible to find any small sections of the mortar in which the hair cannot be seen. This will require from one and one-half to two bushels of hair to a cask of lime.

If the mortar is to be used as a first coat on stone, brick, or similar surfaces, it will carry more sand, and hair is not considered so essential, a half-bushel to the barrel of lime being generally ample. If too little sand is used, the plaster is liable to dry too quickly when setting, and, after it is dry, will crumble very easily, showing up too white, or ashy gray, in appearance. If too much sand has been used, the plastering is liable to fall off, and will crumble when rubbed between the fingers.

Mortar for a second coat on lath may be of about this same consistency of mixture. For the final coat (the *putty* coat or *hard finish*) but very little sand is used. The harder the finish, the less the amount of sand. For this coat, the sand is mixed at the time when the putty is run off. For hard finish, when marble dust, brick dust, or anything of that sort is added, it is generally mixed together on the mortar-board immediately before applying. Stucco, or plaster of Paris, is never mixed with putty until immediately before using, on account of its rapid setting, which occurs in a few moments after mixing. When once set before being applied, it becomes useless. No more water than is necessary should be added, either in the mixing of the mortar at first or in its subsequent tempering, as over-much wetting of the lime deprives it of a considerable proportion of its strength, and also retards the setting process by giving that much more moisture that is necessary to be disposed of by evaporation or crystallization.

A bushel of lime is standardized to weigh 80 pounds; 200 pounds is allowed to the barrel; a bushel contains about one and one-quarter cubic feet. A barrel of sand is supposed to contain 3 cubic feet of sand, and a bushel of sand weighs about 120 pounds, and wet mortar 130 or 132 pounds. When hard, mortar is figured to weigh about 110 pounds to the cubic foot.

To summarize—one barrel of lime, 200 pounds, will take about a cubic yard of sand. In most localities a load of sand is supposed to contain twenty-seven cubic feet, or a cubic yard; but it is frequently less than this, extending down to two-thirds of the amount. To the barrel of lime should also be used about two barrels of water and—as we have seen—upwards of two bushels of hair for a first coat. Hair comes in paper bags weighing generally something under eight pounds and containing enough hair to beat up into a measured bushel. This amount of material, when the lime has been slaked and the whole mixed together, will amount to 35 or 40 yards (about 5 barrels) of mortar; and the amount should cover about 40 square yards of lathed area, requiring about 600 laths to surface.

The final skim coat is mixed roughly to the following proportions: A cask of lime to a half-tub of water, which should take up about a barrel of the hard, clean sand used in the surface coat. It should be remembered that the bulk of the completed mortar mixture does not equal the total combined bulk of its various ingredients, but is less than the aggregate bulk by about one-quarter.

PLASTERING

Interior plastering is now applied either in two or in three coatings. Three coats are always necessary on metal or wire lath, the first coat being required to stiffen the body of the material sufficiently to allow thorough working of the remaining coats. Even upon wood laths, three coats make a better job of plastering than two. Extra strength and body are obtained by the addition of the extra coat, provided time be allowed to dry out each of the coats thoroughly before the next coating is added. It has now, nevertheless, become the general custom to employ but two coats on the less expensive grades of residence work.

The plaster mortar is applied to the walls with a hand trowel of steel, about four and one-half inches wide by twelve inches long, having a wooden handle that is parallel with the back of the blade. After the mortar is put on and roughly smoothed out with the steel trowel, the *darby*, a long wooden trowel, about four inches wide and three feet in length, is taken by the workman and used—with a scouring motion—to level the plaster surface and work it to an even thickness and uniform density. In first-class plastering, all surfaces are trued up in the brown coat with long wood straight edges in addition to using the darby. The straight edges are run back and forth on the walls between the wood grounds provided by the carpenter, and on plaster screeds formed on the ceilings, or elsewhere where the wood grounds are insufficient to form lines for the finished surfaces. Straight edges vary from 6 to 10 feet in length.

Three-Coat Work. The best interior plaster work always used to be put on in three coats, and was worked to a final thickness of about seven-eighths of an inch. Of the three coatings, the first is the thickest, so that, when dry, it may be strong enough to resist the pressure of working the coat or coats to follow. A large part of the advantage of three-coat plastering is obtained by thoroughly drying each coat out before applying another, thus securing the added density and strength made possible by forcing the subsequent coating firmly and strongly against the surface upon which it is being placed. Rubbing or troweling up the rough mortar before it finally dries and sets, also makes it much more compact than is possible from working it at the time when it is first applied.

The first coat, called the *scratch coat,* contains the greatest proportion of hair, that being useful in strengthening the key or clinch of the plaster behind the edges of the wooden laths, through the crevices between which it has been forced. Before this coat thoroughly dries, the surface is *scratched* (hence its name) with a tool designed for that purpose. The surface of the second coat also is sometimes scratched with nails set into a wooden float or darby like that used to rub over the surface, before adding the finish coat. When one coat is entirely dried out before another is applied, this scratching is always necessary, the scratches forming a clinch or tie permitting the subsequent coat to unite the more firmly to the preceding.

The second coat generally contains a larger proportion of sand and much less hair than is necessary in the first coat. The surface of this second coat—or *brown coat,* as it is called—must be brought up true and even, especially at all angles, and be plumb upon the walls. To secure this result it is necessary to use straight edges to true up all surfaces. Before the finishing coat is applied, lumps must be removed and all other imperfections corrected, and the mortar must become sufficiently set to allow the entire surface to be rubbed up with a float or darby and so made compact and firm.

To save time, the plasterer adopted the custom of putting his second coat on over the first while the latter was still green. The combined mass was then darbied and treated the same as in two-coat work, over which about the only advantage of this method was in providing a rougher sand surface on the second coat than was possible when more hair (always necessary in first coat) was included. Otherwise, substantially the same results as are secured by thus working two coats together are obtained in the first coat of ordinary two-coat work, at a saving of both labor and time. While this method does not furnish so good or so permanent a job of plastering, it is modernly considered as meeting the requirements of three-coat work, when so specified.

The saving in this sort of three-coat plastering is made chiefly by the plasterer, in the expense of doing his work. The owner pays more money than a two-coat job would cost him, and actually receives substantially the same grade of work. The second coat, too, dries more slowly when applied before the first coat is dry and hard, and there is therefore not so much saving in time as is generally believed. If three-coat work is attempted at all, it should be insisted that the first coat be thoroughly dry before the second is added.

The final coat is generally composed of lime putty, with a small proportion of white, clean sand, gauged with plaster of Paris. This gives the whitest finished surface. If a color is considered desirable, a colored sand may be used. All lath cracks or settlement cracks occurring in the previous coats should be cut out and patched before the last coat is applied. The final coat is about one-eighth of an inch thick, and the surface is burnished with the steel trowel to an even and straight surface, and worked sufficiently to free it from chip cracks or other surface defects. The lime for the white finish mortar should be run through a sieve of not less than ten meshes to the inch.

From thus combining the first two coats when green, the next step naturally, in the development of methods of work, was to apply but one coat, making it of increased thickness, and scratching it ready to receive the finish skim or white coat, except when it was desirable to finish the plaster with a rough surface, or to *sand-scour* it, as the last process is sometimes called.

Rough Plaster Finish. If the mortar is to be finished with a sand or rough finish, two coats are applied.

The second coat—which should be put on only after the first is thoroughly dry—is substantially the same as the brown coat described above, the rough finish being secured by working the surface of the second coat, before it dries, with a soft-faced float and a mixture of sand with some lime added. Sometimes the surface of the float is of carpet or felt, sometimes of cork or other soft wood. Only so large a surface as may be readily covered at one time, can be floated, darbied, etc., before it has time to set. In this case no hair whatsoever is put in the second coat, as the hair destroys the evenness of the surface that is obtained by the scouring action of the particles of sand rolling around between the surface of the float and the face of the plaster. A long float is generally used for scouring, and the surface is worked to an even and true face, care being taken not to leave any marks from the instrument itself.

While it is generally the custom to add rough plaster finish on the second coat, in inexpensive work, especially for summer residences, a very artistic effect can be obtained by rough-working the surface of the first coat. If one-coat finish is employed, hair must be used, and the consistency of the coat must remain much the same, whether it is surface-finished or not. In that case, however, it is not possible to work the surface as true and as even as the surface of a second coat.

Two-Coat Work. Most plaster work now consists of only two coats. The brown mortar employed for the first coat should be made of fresh lime used as soon as it is stiff enough to be worked, with strong, well-distributed cattle hair and coarse, clean sand. The first coat of mortar must always be put on with sufficient pressure to force the plaster through between the laths, and so ensure a good clinch. The face of this coat must be made as true and even as possible on surfaces and angles, and plumb on the walls. After the first coat is sufficiently set, it may be worked again with a float consisting of a piece of hard pine about the size of the trowel. Sometimes the face of this float is covered with felt or other material to produce a rough textural treatment on the plaster surface. The first coat should run a strong one-half inch in thickness measured from the outer surface of the laths and should be thoroughly dried out.

It is generally inadvisable to attempt to trowel a two-coat job very smoothly. If the attempt is made to float the first coat when it is too thin or insufficiently set, the instrument is likely to leave marks on the wall, and the plastering is itself likely to crack. It is better to err on the side of caution, as, if the plaster has become slightly too dry, it may easily be dampened by sprinkling water upon it with the plasterer's broad calcimine brush and following it immediately with the float. The use of water in this way has accompanying advantages in that it tends to harden the plastering and to prevent the hairs gathering along the edge of the float, when otherwise they would have to be shaken off every few moments to prevent their rolling under the instrument and being pressed into the surface of the plaster in tufts and rolls, in such a way as to show through even the finish coat.

Care should be taken to see that each coat invariably is absolutely dry and hard before the addition of another coat is attempted. Otherwise the later coat will fall off, in greater or less part, and it will be quite impossible ever to obtain a good surface finish; while, if it should happen that the first coat is only partially dry when the second is applied, it will be seriously injured by the pressure brought upon it when floating. Its clinch to the lath is thus often partially or wholly broken, sometimes the plaster falling entirely off, leaving the laths exposed.

The finish second coat in two-coat work is the same as the final skim coat in three-coat work.

The Finish Coat. The *finish, skim,* or *white coat* should never be applied until the earlier coat or coats are thoroughly dry and hard, as it is liable to crack if put on before—quite aside from the possible danger of injuring the first-coat work by the pressure of troweling before it is entirely dry and set. A simple putty coat should carry more sand than when the finish is hardened by the addition of plaster of Paris. If plaster of Paris is used, the mortar should always be *gauged* (that is, plaster of Paris should be mixed with the putty) *after* it is placed on the mortar-board. The usual process of gauging consists in making a hollow with the trowel in the midst of the pile of lime putty lying upon the mortar-board. This hollow is filled with water, and the plaster of Paris sprinkled upon it, the whole then being mixed rapidly with the trowel and put upon the wall immediately, before the plaster has time to set. The proportion of lime and plaster of Paris, while variable, averages probably one-fourth to one-fifth plaster of Paris.

The finish is skimmed in a very thin coating that is generally less than one-eighth of an inch in thickness. It is immediately troweled several times, dampened with a wet brush, and thoroughly troweled to smooth up the surface and prevent it from chipping or cracking. The water prevents the steel trowel staining the surface, but the plaster should not be too wet, as it will then blister or peel. The whole surface of the finish coat, whether of putty or hard finish, should finally be brushed over once or twice with a wet brush; while, if a polished (or buffed) surface is required, it may be gained by brushing—without dipping the brush into the water —until a glossy surface is obtained.

Especial care should be taken, in the final coat, to finish all joints smoothly and evenly so that the point of jointure will not be apparent. The ceilings are completed first; then the upper part of the wall; and lastly the bottom portions which can be reached from the floor and thus more carefully finished up to the joint.

The plasterer generally scaffolds the room with boards at a sufficient height to enable him easily to reach the ceiling overhead without raising his arms too high to work each of the coats evenly. The plaster is applied on the upper part of the walls from the same scaffolding, and the remainder of the work is completed from the floor. If too much time elapses in joining the coats at this point, the joint is likely to show—which is, of course, not serious unless the walls are to be left untreated. Occasionally two men working along together, one on the scaffolding and one on the floor, finish the walls at the same time.

As the scratch coat is used principally to insure a clinch back of the lath and to provide a surface to receive the brown coat, if plaster is applied on a stone or brick wall or on tile, a scratch coat is seldom necessary; and the coat of brown mortar is very often used without hair and of about the composition of brick mason's mortar. If a scratch coat is used under these conditions, it is generally mixed with more sand and less hair than when put upon laths.

For a finish where plaster mouldings are to be used, or when for any purpose an unusually straight, level, and plumb surface of plaster is required, three-coat work, put on in the old-fashioned manner and trued up with straight edges, should be demanded. This is necessary in order to get a surface sufficiently level and true to run plaster mouldings evenly, and to avoid the inequalities that are almost certain to occur in all two-coat plastering.

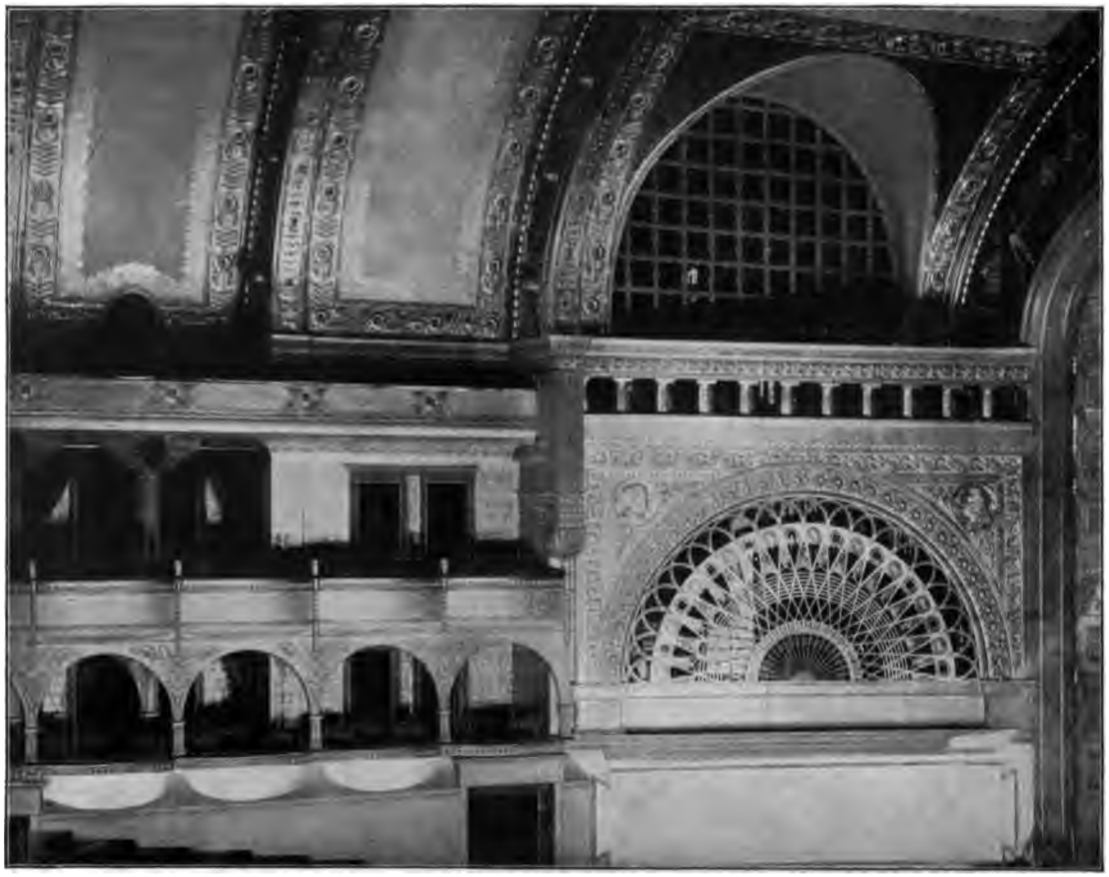
The second and third coats allow opportunities to obtain a straight and level plaster surface. Individual spots are brought up to an even surface, the plaster then being added and carefully worked between and amongst them, bringing it all to the same face by means of the straight edge. Occasionally it happens that the rough coat is so uneven that some filling in is absolutely necessary to make the wall sufficiently even to receive the last coat. In that case, a mixture of half plaster and half putty may be used in leveling up the rough work. If no finish coat is to be put on, the surface should be troweled smoothly as the mortar is applied, care being taken to leave no marks, hollows, or uneven places; but if the wall is to be finished or frescoed, it should be left with a floated surface.

Patent Plasters. Patent plasters, such as adamant, etc., are not often employed for private dwellings, being chiefly suitable for mercantile purposes. The patent plaster has certain advantages that are self-evident—such as quick drying and hardening. Its surface hardens more quickly and resists abrasure longer than the ordinary lime plastering. However, a break once occurring, the extreme stiffness of the mixture makes it liable to extend further and to be of a more serious nature than if the softer, more flexible lime plaster covering had been injured in the same manner.

The extra stiffness of most patent plasters is caused by the cement that generally forms an important part of their composition. These plasters are sold ready for use, requiring merely the addition of a sufficient amount of water. They are therefore especially adapted for use by the inexperienced, and are valuable for executing small pieces of work, as they do not present the liabilities to failure, or loss of time and delay, occasioned by mixing up batches of lime mortar. On account of the quick setting properties of patent plasters, it is inadvisable to use them on wood lath, as the subsequent drying and shrinkage of the lath will almost invariably cause cracking of the plaster

Back Plastering. Occasionally a wood-framed house is *back-plastered* for warmth. This process consists in nailing a strip of seven-eighths inch furring against the inside of the boarding on each side of the studs. The space between the studding is then lathed (of necessity a slow and bothersome job) and plastered one rough coat of hair mortar, which should be allowed to dry before any lathing is placed over it on the inside face of the studding. As a matter of practice, the efficiency of back plaster is much injured by the fact that the studding, in seasoning after the plaster is set, is likely to shrink away from the plaster, leaving a narrow perpendicular crack on each side of the stud, which permits of the passage of cold air.

Plaster Cracks. Cracks in plaster occur from several causes. If the distance between the ends of the laths, where they join on the studding or furring, is too great, the larger amount of plaster in that place, when drying out, may cause a short crack. Any such spaces should, however, be filled by the lather before plastering is begun. Sometimes, too, especially in the first coats, cracks are caused by the shrinkage or expansion of the wooden laths after the mortar has



CORNER OF INTERIOR OF AUDITORIUM, CHICAGO, ILL.

Adler & Sullivan, Architects, Chicago, Ill.

The Decoration is Based on Byzantine Motifs. The Stage Opening is on the Right.

wholly or partially set. The result is a series of narrow cracks parallel to each other and the width of the laths apart. *Lath cracks* are ordinarily filled in and covered up by later coats, and so do not often appear in the finished plastering. They may, too, be worked out when floating up the coat before it finally sets. If wide or deep, however, they should be cut out to a width of an inch or so, and filled in with new mortar before adding the last coat.

Cracks of a like appearance are sometimes caused by the rough mortar being too rich, or by draughts of air from open doors or windows drying out portions of the plastering too quickly. The too rapid drying of plaster with stoves or salamanders, often produces a like result from similar causes. An experienced plasterer should be able to determine the responsible cause and take measures accordingly, using more sand if the mortar is too rich, screening openings to prevent draughts, and using less fire in his drying stoves. In green work, damage already done may be repaired by refloating again before the work becomes too dry, softening the mortar with water if necessary.

Cracks sometimes occur in the angles at the ceiling or corners of the room. When in this location, they may be caused by the shrinkage or settlement of the partition or floor. In the perpendicular angles, especially, they may extend only to the depth of the finishing coats. In that case, the causes are likely to be either too thick plaster, insufficient troweling, or an insufficient amount of plaster in the gauged coat—causes which are easily remedied in the remainder of the work.

Cracks running diagonally across a partition, or radiating from the corners of doors and window openings, are caused by the unequal settlement or shrinkage of the building. They frequently occur at a perpendicular angle where a wood partition is brought up against a brick wall, or at the ceiling line where a wooden floor comes up against a brick supporting wall.

Cracks occur in the final finish when the putty is not gauged enough or not troweled or brushed enough, when it is put on too thick, and when too little sand has been used. These cracks are called *chipped cracks*. Plaster, when apparently perfect and without cracks, will sometimes crumble, either from too rapid drying or from the use of too much sand. Either too much or too little sand materially injures the strength of mortar.

If unclean sand, dirt, or clay has become mixed with the mortar, it not only weakens the lime but prevents its adhesion to the sand particles, so that no real set of the mortar ever occurs. Of course, at all times, poor materials—sand, lime, or hair—may be responsible for defects in plastering. Plaster occasionally falls off even when apparently hard and good, if the laths are too near together, if there is insufficient hair, if the mortar is too rich or too sandy, or if it had not been pressed against the laths with sufficient force when being applied; or it may become loosened by the springing of the laths under the pressure of floating it too hard. On brickwork the mortar requires considerable more sand than for application on laths.

Lime must have time to set before it dries out. Therefore, to last well, it should dry slowly. A stiffer working mortar makes better and harder plaster than thin or wet material, provided, of course, it is thin enough to clinch well to the lath in first-coat work, or to adhere to brick and dry scratched surfaces, and to spread evenly, in second-coat work. Stiffer mortar can safely be applied upon wet mortar than on dry; and wide-spaced lathing will take stiffer mortar than close-laid laths. When two coats of mortar have been put on, and the last coat falls from the first, it is generally because the first coat was not wholly dry when the second was applied. The coats must either be entirely dry or quite green to be successfully combined.

If possible, it is better to have the workman use makes of materials, especially lime, having those properties with which he is acquainted. Attention has already been called to the fact that different makes of lime vary considerably in their chemical composition. It is not even certain that lime of the same make will always run even in production, year after year. Of course, lime that has been slaked by exposure to air or water while in the barrel, and before it is used, is worthless. As this occasionally happens, it is well to be watchful and see that such bad material is never added to the plaster bed.

As a final warning, be certain that the last coat of plaster has dried out hard and strong before any wood finish is installed, as otherwise the wood will absorb the moisture from the plaster, causing it to swell and therefore opening cracks that are never likely afterward to be altogether closed. All wood finish should also be kept out of the house while plastering is going on, as it will absorb moisture from the air around it. The reason that sash are not ordinarily set until after the plastering is finished, is because they absorb so much of the moisture as to cause the sash to swell in place. It is generally considered preferable to fill the window openings or doors with screens of cotton cloth, as this prevents direct draughts and still allows of a circulation of air that dries plastering much more rapidly than artificial heat, or than it would dry if these openings were closed by solid doors and glazed sash. In very bad weather the screen of cotton may be slightly strengthened, if necessary, by the application of a coat of whitewash on the inner side. Contrary to what might be supposed, the cloth window-screen is almost as good a protection against external cold and frost as is the glazed window, although the current of air passing through the cloth meshes of these screens into and out of the house, causes a slight loss of heat, adding somewhat to the expense for fuel required to dry out a plastered building. In good drying weather, these screens should be taken out and left out during the day, but should be replaced at night or in damp weather, when the plaster otherwise is likely to reabsorb moisture from the air and so delay the time of its final drying out.

If avoidable, the artificial drying of plaster by salamanders should not be employed; natural drying by sun and air is, under all circumstances, preferable. The salamander not only dries the room in which it is placed, too quickly—especially the ceiling above—but fills the air and the plaster itself with gas fumes, and, by steaming, is frequently the cause of the rotting of plaster or hair, thus reducing its vitality and life. Heating a house to dry out the plaster by means of the regularly installed heating plant, is preferable to the use of salamanders, the chief objection in this case being occasioned by the unduly rapid drying-out of wall plaster back of or above registers and radiators. The situation is helped if the radiator is set out from the wall and some screen is placed between it and the plaster. A screen may also be employed against the wall over a hot-air register; but there is no means of protecting the plaster on either side of a partition through which a hot-air or steam pipe passes. Such plaster is bound to be severely strained by being dried too quickly.

If plaster is frozen when wet, it is likely to loosen up and injure the whole mass so that it may eventually fall off. The effects of freezing are less troublesome if the wall is frozen after it is dried and has once set. If only slightly frosted, and thawed immediately and floated again, it may often be saved, the effect in that case being not much different from what it would be if the wall had been surface-moistened and refloated.

Plaster Moulding. Plaster mouldings upon ceilings and walls are less frequently employed now than a few years ago, when, especially at the intersection of wall and ceiling, a heavy cornice of plaster was the common method of finish. Nowadays a cornice of wood is more commonly used.

Briefly described, the running of a moulded plaster cornice is as follows: Two parallel strips, or *screeds*, of plaster, are run on the ceiling and the side wall, with their nearer edges evenly straightened. These edges are then fitted to the mould—a piece of metal cut out to a reversed section of the cornice outline. The mould is run along the strips fastened to the wall for guiding it, the lower edge being cut out and fitted to run upon them.

The plaster necessary to fill up the mouldings of the cornice may be tied back to the wall and ceiling by rows of nails driven so as to stand at about the location of its greatest thickness; while a strip of metal lath, filling in the angle upon projecting furrings, will offer the best possible clinch, and will help to reduce the thickness of the plaster and render its drying and shrinkage more equable and its surface less likely to crack.

When all is ready, enough putty and plaster are gauged in about equal parts to run the cornice down the length of one side of the room. The moulding form is then rested upon the supporting and guiding strip against the wall, and drawn along from right to left, pressed against the mass of mortar which is thrown into the angle just ahead of it by the trowel, the space immediately in front of the moulded strip being kept sufficiently full of plaster mortar to fill out the moulding entirely at all times. When the length is completed, or the gauged material is used up, the mould is moved back and forth along the length of cornice that has just been run, scraping away all the plaster except that included within the outline of the mould.

Where hollows occur, the gauged material scraped off by the mould should at once be thrown on again at these places, so that they may be immediately filled and brought up to the right section outline by again running the mould over these portions. The gauged putty will set in a few moments, and each side of the room or section of the moulding must be run and completed or filled out very rapidly. The corners at the angles of the room may be filled in by hand, or a section of the mould may be separately run upon the floor, sawn in a mitre box, mitred and fitted in place upon the wall, the joint between the cast and run moulding being then carefully patched and evened off.

The extra amount of plaster included in the thickness of extreme projecting mouldings is the cause of occasional surface cracking; while other cracks are occasioned by the settlement, shrinkage, and movement of the house frame. For these and other reasons, it is now generally considered that a wooden cornice, despite its defects of shrinkage, is better suited than plaster to this purpose.

Finally, the moulding may be sprinkled with the brush and the mould may be run over it several times more, ending by finishing with a brush so as to give the moulding a gloss just as on the wall plastering. The same process is repeated for different kinds of plaster moulding, merely varying the method to provide for the different conditions set by circumstances, a circular moulding around the lighting outlet in the middle of the room, for instance, being swung from a peg driven into the center of the gas pipe or outlet box. Other kinds of plaster mouldings are run by unimportant variations of the processes described.

Cast ornaments are made separately in moulds, into which the plaster is poured. Most of these separate moulds are made of plaster hardened with glue or shellac, or surfaced with beeswax, and are generally oiled before being used. Plaster ornaments are fastened in place with fresh plaster or glue; occasionally a few screws are used, in which case the heads should be countersunk and covered in with plaster so as not to show.

EXTERIOR PLASTERING

Although exterior plaster surfacing for dwellings has been in use in Europe for many years, it has but recently met with favor in this country. In Italy, plaster, or stucco, applied in large, unbroken expanses upon a stone or brick building, has long been a favorite method of construction. Frequently, too, this plaster surface is stained or colored and worked up into different designs. In England, France, and Germany, plaster has been more frequently used in connection with a half-timbered frame, although these countries also contain instances of its use in large, unbroken, simple surfaces.

In modern American work, it is not often that a brick wall is covered with plaster, as the æsthetic possibilities in the use of rough hard-burnt brickwork have now long been recognized; and when this—the cheapest brick-building material—is employed upon a dwelling, it is itself utilized for the exterior surface and to obtain the exterior effect of the structure.

Plaster has been used in this country in imitation timbered houses for some years; but recently its employment in large, simple surfaces, unbroken by the cross-barring strips of dark wood, has become popular—a treatment much more appropriate to this country. We also possess some examples of brick and stone houses, two hundred years old or thereabouts, that were covered and surfaced with white plastering; but in the most recent of American plastered dwellings, this effect has been simulated by applying the plaster to a wooden frame lathed with a fine-meshed wire cloth.

In any plastered building, the cornices should be projected sufficiently far to protect the walls and all exposed upper surfaces of the plastering. The farther this projection, the more certain the safety of the plaster, especially in the northern sections of the country.

The essentials for successfully-wearing exterior plaster applied in modern fashion, are: A well-seasoned, shrunk, and settled frame; a solid, immovable foundation; and a carefully applied and thoroughly worked job of plastering. The framework should be somewhat better constructed and more carefully arranged to prevent movement or settlement than on an all-wooden building. Other than this, the dwelling to be plastered outside does not differ, in any part, from the ordinary house, until the structure has been framed and boarded in. For plastering, the boarding is then covered with a slightly better and more waterproof grade of paper than if shingling or clapboarding were intended. Outside of this papering, the house is furred with strips of furring, seven-eighths of an inch thick by one and one-eighth to one and one-quarter inches wide (for metal lathing they are to be placed nine inches apart, for wood laths twelve inches, on centers), and the lathing is applied upon these strips.

METAL LATH

The best lath for exterior plastering is probably No. 18 gauge wire cloth with a ⅜-inch square mesh. The wire is sufficiently large to be durable, and the mesh sufficiently open to allow the mortar to press through and completely fill and close in over the back of the wire, thus protecting it from exposure to the elements or damage from water and rust, even if the plaster surface should leak sufficiently to admit water behind this covering. Expanded metal is also used for this purpose, but it is not generally considered so good a material, from the fact that it is impossible to cover entirely and protect the back of this lath with plastering, and therefore there is no means of certainly protecting it from the possibility of rusting.

Occasionally, on a small, low house of not over a story and a half of wall height, the boarding may be omitted altogether. The metal lath is then placed directly upon the furred studs, and plastered both outside and in to insure its absolute protection from damage by water. However, the shrinking of the studs opens a small crevice along each side—which has already been mentioned as occurring in back plastering—and it is thus possible that water may enter from the back and do considerable damage, even through the narrow space that this shrinkage provides. The omission of the outer boarding also somewhat injures the stiffness of the house, as a frame constructed in this way is not so well braced as when the boarding is applied. Neither are the dwellers in the house so completely protected from the exterior weather, as the second air-space obtained between the papering and the exterior plastering is lost. This extra air-space is of assistance in keeping the house more equably warm in winter and cool in summer.

In the use of metal lath, it is always to be remembered that the *absolute* essential is to protect the lath from the action of water and rust. In all cases the lath should be galvanized or thoroughly coated with a waterproof paint or compound. This once done, a permanent plaster surface is ensured. Sometimes the metal lath is wired and fastened to perpendicular iron furrings of tee-irons held to the wood frame with staples, allowing any possible movement of the frame to occur without straining the plaster surface, which is by this means disassociated from, while directly supported by, the house frame. Cracks around the windows and the angles of the buildings are thus prevented; but it is a more expensive form of construction, and is not now employed except in the larger and more expensive residences.

From the use of wire lath, there are occasionally obtained small surface cracks, especially if the lath joint happens to come at a place where some strain is afterward placed upon it, and particularly where it is weakened from the movement of adjacent portions of the building. For instance, if a perpendicular lath lap is made on the line of the edge of the window finish, a crack on the line of this joint is almost certain to appear in the plaster, extending both above and below the wood-surrounded opening. Care should be taken to cut the strips of lathing so that the joint will come at least nine or ten inches on either side of the edge of the window or door finish. All furrings should also be kept away and back from all angles, internal or external, upon the walls, so that a certain clinch may be effected by the plastering at these important points.

WOOD LATH

Wood lath is occasionally used, and, in certain sections of the country, apparently with good results. It may be employed in two ways—one, in the ordinary manner, only spacing the laths somewhat further apart than would be advisable on the interior of the dwelling. The other method consists in laying the laths diagonally over the building in such a manner as to form a criss-cross lattice-work. In this case the distance between the laths is from three-quarters to seven-eighths of an inch, so as to allow the plaster to enter easily and form a solid clinch behind these lattice openings. The purpose of the diagonal criss-cross lattice is to provide more or less flexibility for the wall covering, so as to take up, without injuring or cracking the plastering, a certain amount of the movement that may always be expected in a wooden-framed dwelling. This method of employing lath, by the way, is in most localities almost as expensive as the use of wire or metal lath, which is probably a safer and surer material to employ. As large and as good a quality of heavy wood lath as can be secured, should be provided for exterior work. Lath cracks are also then to be expected, from the same reasons that apply to interior work; while the mortar should be somewhat softer and slower drying when used upon this material than when employed upon a metal surface.

If possible, it is advisable so to arrange the work upon the house that, after the completion of the frame, some time will still elapse before the plaster is applied. If the frame can be boarded in, and the interior of the house plastered and finished under artificial heat during the winter, and the exterior plaster added in the spring, probably the best results are to be expected. Opportunity is then provided for the frame to shrink, settle, and contract. Most of the weight to be placed inside of the building is then also installed before the exterior surface is applied, so that much less strain and movement may be expected afterward to affect it than would be probable under the opposite conditions.

PUTTING ON THE PLASTER

Exterior plaster requires three-coat work. The first or scratch coat is indispensable when metal or wire lath is used, but almost equally important over wood lath. This first coat should be scratched or roughened while drying, and must be thoroughly dry before the second coat is applied. A greater time ought to elapse between the applications of exterior than of interior plaster coats, inasmuch as it then becomes possible to cut out many of the larger and more important cracks than have had time to appear, and to patch them before the second coat is put upon the house. The second or brown coat is then the less likely to crack; and, if a further extra time is allowed the plastering to dry, it can also be patched at the last moment before the final slap-dash or finishing coat is put upon the walls. This slower progress aids in giving a more permanent job and one that is at the same time less likely to give annoyance from surface cracks afterward making their appearance in the finish plastering.

The question of proportion in mixing the plaster is quite as variable here as in the case of interior plastering, and it is equally impossible to give absolutely definite directions. Different plasterers, each being guided by the experience obtained from working in different sections of the country, prefer their individually different ways of proportioning or mixing their materials. In the first coat, cement is added to the lime mortar in proportions varying between ten and forty per cent of the mixture. Some plasterers prefer that the first coat should be less stiffened with cement than the second. With others the reverse is true; while, contrary to the general supposition, the exterior coat appears—in the majority of cases—to contain only that amount of cement necessary to provide the tone or color that is desired for the exterior treatment. Conditions also greatly affect these proportions. When the plaster is added last on a well-seasoned and shrunk frame, for instance, it is worked stiffer than when the building is newer and still far from finished.

The final coat for exterior plaster is generally applied as a *slap-dash* finish, the surface texture being given by the throwing of handfuls of variously sized pebbles or gravel upon the fresh outer coat, thus pitting or marking up its surface. The smaller the size of the particles employed for this purpose, the more likely they are to stick and remain in the fresh putty, slightly tinting the surface with the color—if any—of the gravel employed.

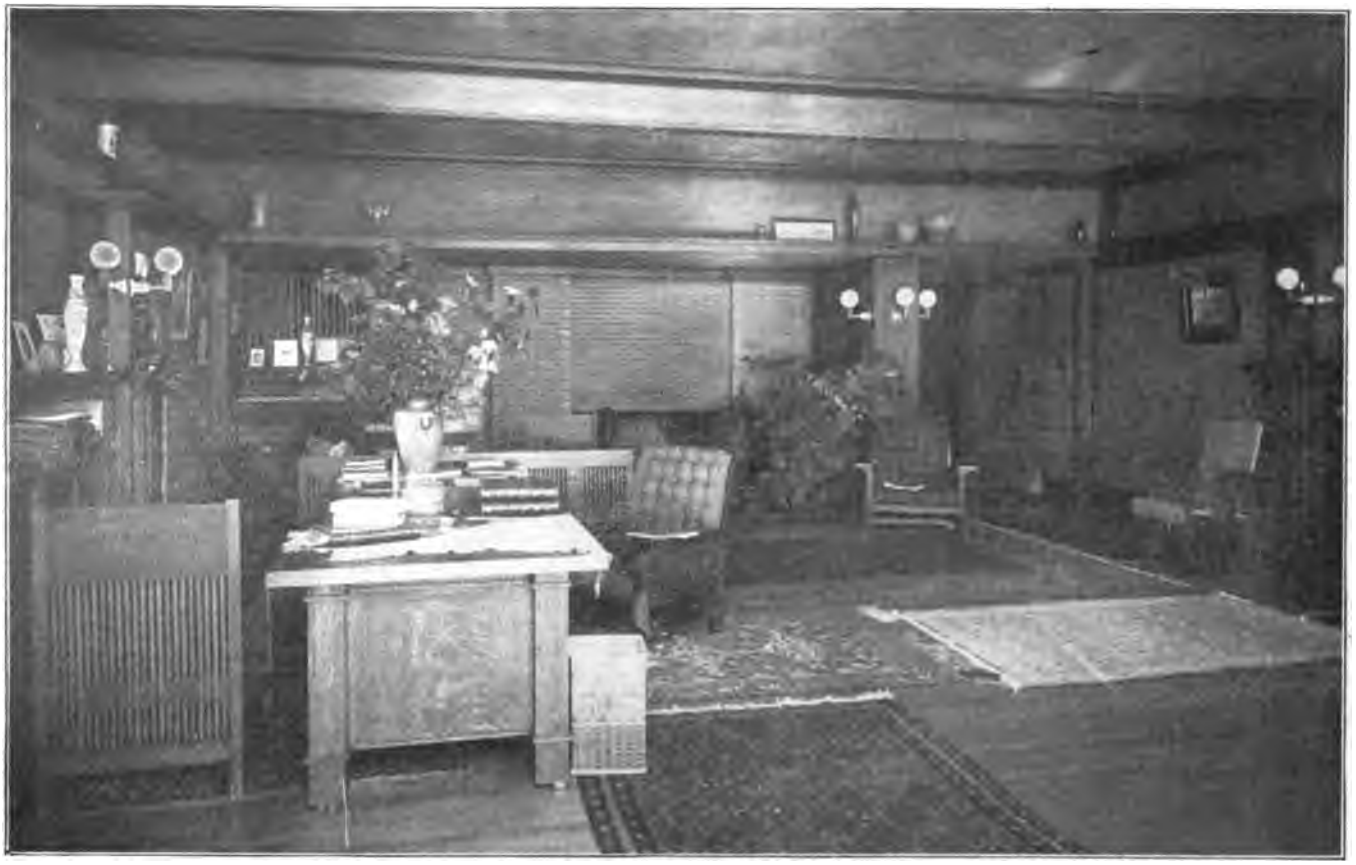
The coloring of exterior plastering is done in much the same way as when it is used inside the dwelling. As a rule, it may be said that not sufficient consideration is bestowed in this country upon the possibilities provided by the use of color for exterior plaster work.

It is agreed that the utmost care to prevent absolutely any leakage is necessary on the part of the workman in the carrying out of this class of work; and it is here that the success or failure of exterior plastering most often hinges. Of course, the joints occasioned by the juxtaposition of the wood finish and plaster around window and door openings offer many opportunities for leakage. The plaster should here be carefully flashed; and, if possible, an outer architrave backband should afterward be put on so as to cover and protect this joint. Otherwise, a key should be provided for the plastering, by cutting away or hollowing out a space near the inner edge of the wood façure, into which the plaster may be pressed by the workman, and leakage thus prevented even if the wood, as is quite likely, shrinks slightly away from the plaster after it has been put in place.

The problem of making tight this exterior plaster wall is complicated and rendered more difficult when it is divided into panels by a so-called *half-timber* treatment. In this style of design, a great number of joints between plaster and wood are occasioned where the wide wood boards are almost certain to shrink away from the plastering, and where, too, it is impossible to protect these joints by outer applied battens in any way capable of covering such an opening as may occur. Thorough flashing on all upper exposed surfaces, assisted by protecting overhang of the roof eaves, and broad keys provided for the entrance of the plaster at all perpendicular and lower horizontal joints, must alone be relied upon.

Under no circumstances, so far as the lasting value of the work is concerned, does the mixture play so important a part as the expending of great care upon the thorough surfacing, working, and finishing of the mortar, pressing it into every crevice provided to receive it, flashing thoroughly every exposed or upper surface provided by the finish, and taking every precaution to work out all pinholes or other defects where water could possibly penetrate the surface. Every care and endeavor is directed to providing a solid, evenly worked, and permanent coating which will, in every possible way, throw off and prevent moisture being admitted into the space back of the plaster coating—that vulnerable portion where its attack is most effectually concealed and most to be dreaded.

The exterior plaster treatment of a cement or concrete wall is a problem that from now on will continue to be of rapidly increasing importance. Here, however, it is but necessary to use the cement as nearly *neat* as possible, adding lime or a make of white cement in case a brighter surface color is desirable. The problem of the æsthetic treatment of concrete construction is one that requires separate and particular consideration. Its solution has, as yet, been hardly attempted. Hollow terra-cotta tile is another material that is being modernly used more and more as a structural base to take an exterior plaster surface finish.



LIVING ROOM IN DWELLING FOR MR. W. W. WILLITS, HIGHLAND PARK, ILL.
Frank Lloyd Wright, Architect, Oak Park, Ill.
Brick of a Brown Color; Woodwork Stained Brown.

PAINTING

Introductory. The first thing a man wishes to know when he contemplates painting a house, is the *cost*. This will obviously depend on the cost of labor, of materials, and the kind of materials chosen. The outside of a house is painted, either in whole or in part; the interior may be painted or varnished. Some houses have their walls partly covered with shingles; these shingles are sometimes painted, and sometimes—in fact, often—left unpainted; but what is called the *trim*—that is, the boarding about the eaves, windows, doors, the base-board, and corner-pieces—is painted. Shingles, either wall or roof, are often stained with a creosote stain consisting of a coloring matter dissolved or suspended in a liquid called *creosote*, which is applied for the purpose of preserving them; and though instances can be cited in which wall-shingles that were never stained are still doing good service although believed to be now two hundred and fifty years old, yet the use of creosote will undoubtedly prolong the life of modern, sawn shingles, as it is noxious to insect life and a powerful deterrent of natural decay. The color of unpainted new shingles is generally disliked; but after four or five years wall-shingles take on a beautiful, soft color. The question of staining shingles is a matter of taste.

Most houses are exteriorly painted with paint based on white lead or zinc. Some idea of the cost may perhaps be gained from the following considerations:

White lead is sold either ground with a little oil to a thick paste, or—less commonly—in the dry state.

A mixture of 100 pounds of dry white lead with 5 gallons of linseed oil, makes 6½ gallons of paint, weighing 21.3 lbs. per gal.

Approximate figures are: 15 lbs. paste lead and 6.3 lbs. oil equals 1 gal. (1 gal. oil equals 7.7 lbs.); 14 lbs. dry lead and 7¼ lbs. oil equals 1 gal.

A mixture of 100 pounds of white zinc and 8⅓ gal. oil, makes 10⅝ gal. of paint; 12 lbs. zinc and 1 gal. oil make 1.3 gal., or 9.5 lbs. zinc and 5.7 lbs. oil make 1 gal. white zinc paint weighing 15.2 lbs. Dark-colored paints made from iron oxides, ochers, and the like, weigh 12 to 14 pounds per gallon; but exact figures cannot be given, as the raw materials differ greatly.

Here should be noted the difference between the priming coat and the succeeding ones. A *priming coat* is the first coat applied to the clean wooden surface; it differs from the other coats in containing more oil, because the wood will soak up the oil and leave the coloring matter of the paint on the outside.

To make the paint for the priming coat, take a gallon of the paint already described and mix with it a gallon of raw linseed oil. Paint thus made is, of course, lower in price; it is also much thinner; but such is the absorbent power of the wood, that the priming paint does not cover as much surface as the succeeding coats per gallon. A gallon of this thin priming coat covers 300 to 400 sq. ft., while a gallon of second or third-coat paint, well brushed out, will cover about twice this surface; this is because the surface for all but the first coat is hard and non-absorbent. Priming coats are used for both outside and inside work, as will be described later.

The dark-colored paints are usually cheaper than those made from lead and zinc, and if made of good materials are not inferior in durability; the extraordinary claims made by the zinc and lead manufacturers are to be received with much doubt. Some of the dark-colored paints are the most durable that can be applied on wood. The chief cost of painting is, however, that of labor, which varies according to locality and other conditions, seldom being less than twice that of materials.

For light-colored paints, it is better to use raw linseed oil to which pale japan dryer may be added, as described later; for dark colors, either this or boiled oil, boiled oil being darker in color. The cost is practically the same; also the durability.

On inside work may be used either oil or enamel paint, as described later, the former being the cheaper, the latter the handsomer and slightly more durable; or the wood may be finished in its natural color, by varnishing it either with an oleo-resinous varnish or with shellac varnish. The oleo-resinous varnishes darken the wood very appreciably, while white shellac varnish keeps it more nearly in its natural color; although the latter does not prevent the natural darkening action of light, it may retard it. Shellac varnish is the more expensive finish of the two, if well applied. What is sometimes called *oil finish* generally consists in the application of a cheap varnish called *hard oil*, which is usually made of common rosin, linseed oil, and benzine. Its only merit is that it is cheap.

It would indeed be possible to apply neither paint nor varnish, but merely to saturate the wood with oil, and this would be truly an oil finish; it would, however, make the wood dark and dingy, and would readily retain dirt, and is a practice seldom followed except sometimes on floors—especially kitchen floors—and sink shelves. These are at frequent intervals oiled with a mixture of equal parts boiled oil and turpentine.

It is the purpose of this Instruction Paper to describe only good and approved methods. It will readily be understood, and will certainly be observed in practice, that these methods may be abbreviated by the omission of some details that are here specified as desirable. For instance, it is difficult to get interior finish sandpapered or rubbed between coats, even if so contracted; but this is the right practice. Two coats of varnish often have to serve in the place of four. No one, however, needs to be told these things. The methods herein described are not luxurious or extravagant; they are, on fairly good houses, truly economical; and we are not considering temporary structures.

It is not uncommon to find part of a house, as the living rooms, finished in varnish, and the kitchen and pantry painted with oil paints, which are lighter in color and more easily renewed. The sleeping rooms, on the other hand, are often finished in enamel paints, because color effects are desired to harmonize with the furnishings; and bathrooms are almost always done in enamel for sanitary considerations. The taste and inclination of the owner are to be consulted in regard to all these matters.

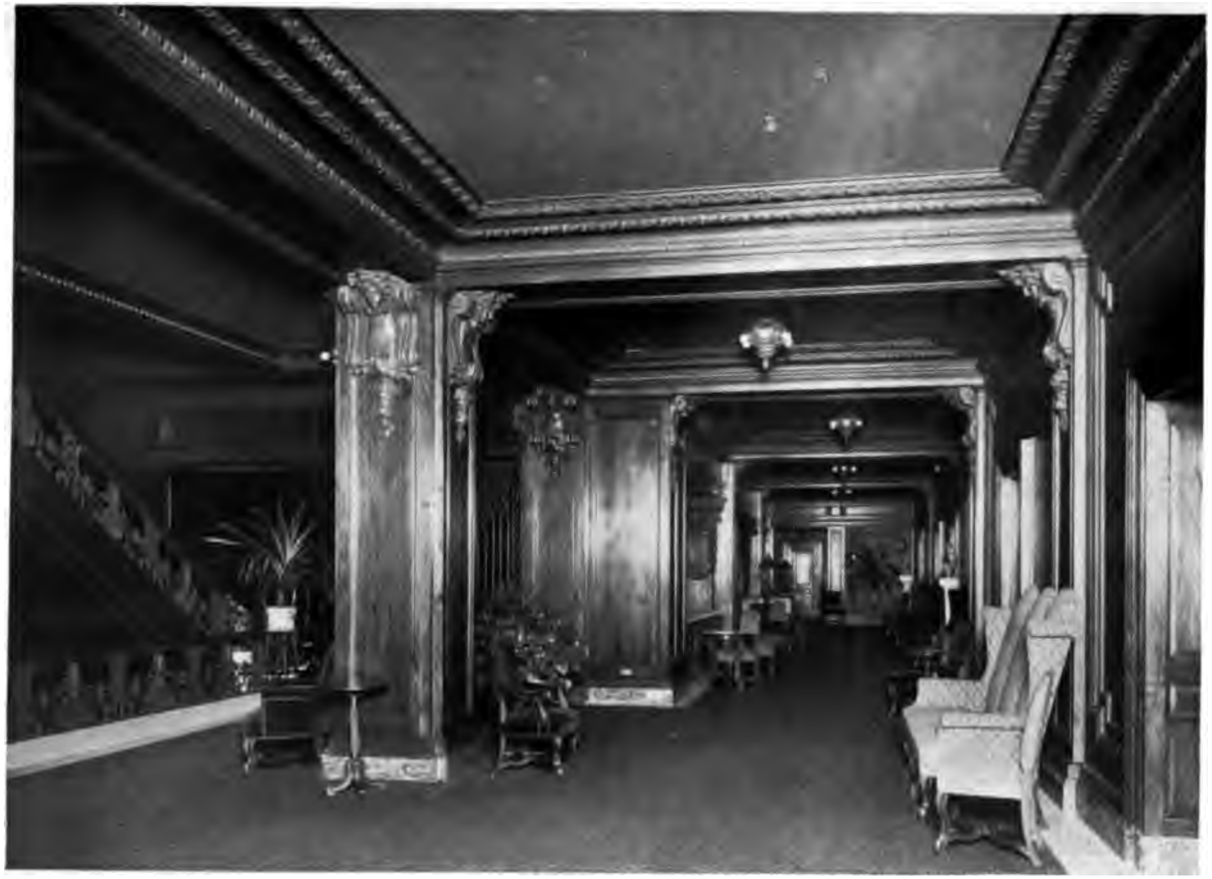
PAINTERS' SUPPLIES

Pigments and Vehicles. Paint is a mixture of a finely-divided solid substance with a liquid which, when spread on a solid surface with a brush or otherwise, will adhere and in a short time form—by evaporation, or more commonly by oxidation—a somewhat hard and tough film. The finely divided solid is called the *pigment;* the liquid part, the *vehicle.* The most common vehicle is *linseed oil.* This is an oil obtained by pressure (or extraction by solvents) from flaxseed. When spread out in a film and exposed to the air, linseed oil is converted into a tough, leathery, elastic substance called *linoxin,* insoluble in water and all common solvents. This change is brought about by absorption and chemical union of the oxygen of the air, whereby the weight of the oil is increased about one-fifth or one-sixth. It is therefore a mistake to suppose that oil paint gets dry as whitewash does, by the evaporation of the liquid. Instead of that, it gets heavier. There are some other vegetable oils which have this property in some degree, but none which are used for paints to any considerable extent; some are used a little for artists' colors.

Linseed oil should stand at least a month or two before using. It should then be perfectly free from sediment or cloudiness; if it is not so, this is a sign that the oil has not been properly aged, and such oil is not fit for making paints. In this natural state, it is called *raw oil;* and the price of linseed oil as commonly quoted refers to raw oil. *Boiled oil* is this raw oil which has been heated, usually to 450° or 500° F., with the addition of a small amount of oxide of lead or oxide of manganese, or a mixture of the two (occasionally some other lead or manganese compounds are used). Boiled oil is darker (browner) in color than raw oil, but differs from it chiefly in that it dries five to ten times as rapidly. A thin film of raw oil on a glass or metal surface will dry at ordinary temperatures in five or six days, so as to feel no longer greasy; but boiled oil will do the same in a day or half a day. Oil dries best in warm, dry weather and out of doors.

The pigment is mixed with the oil by stirring the two together. This is usually done by power, in a vessel called a *paint mixer.* The mixture should then be run through a *paint mill;* some paint mills are of steel, but the best have a pair of mill-stones, between which the paint is ground and most thoroughly mixed. Paints mixed in this manner are much better than those which are mixed only by stirring.

Besides oil and pigment, paint sometimes contains a volatile *thinner,* the most important thinners being *turpentine* and *benzine.* Turpentine is a well-known essential oil, volatile, boiling at about 320° F., but evaporating at ordinary temperatures when exposed to the air. Benzine is a mineral oil, lighter than kerosene and heavier than gasoline; the kind used in paint and varnish is called "62-degree benzine," its specific gravity being 62° on the Baumé scale for liquids lighter than water. Linseed oil weighs 7.7 lbs. per gallon; turpentine, 7.2 lbs.; and 62° benzine, 6.1 lbs. But linseed oil is sold by the oil makers and dealers on the basis of 7.5 lbs. per gallon.



HEAD OF MAIN STAIRWAY AND CORRIDOR IN LA SALLE HOTEL, CHICAGO
Holabird and Roche, Architects, Chicago

Paint brushes are *round, flat,* or *oval.* A favorite brush for ordinary outside work is what is called a *pound brush,* a large, round brush with stiff bristles six inches long. Such a brush should be *bridled* when it is new—a "bridle" being a piece of cord wound around the bristles to shorten their effective length; as the bristles become worn off, the bridle may be removed. A 2½-inch oval brush (2½ inches wide) is a highly satisfactory tool to use in general painting, and is the brush recommended by the paint committee of the American Society for Testing Materials. It is worth noting that this committee, made up equally of expert paint manufacturers and experts employed by the large consumers, unanimously agreed that no larger brush than this should be used in making paint tests.

The use of brushes five inches wide is common for outside work; but while such brushes may be had of the best quality, they are heavy and laborious to use, and the workman who uses such a brush will not brush the paint sufficiently to get the best result. If a flat brush is used, it should not exceed 3½ inches in width; and three inches is better. A good 2½-inch oval varnish brush is a most excellent brush for all large work in either paint or varnish. The painter should also have a good 1½-inch oval brush for smaller work, and a number of round or oval brushes, called *sash tools,* of different smaller sizes, for more delicate work, such as sash and frame painting. Stiff-bristle brushes, which have been worn off short, are suitable for such work as rubbing-in filling. For varnishing large surfaces, flat bristle brushes 2½ inches wide are good; also similar ones 2 inches, 1½ inches, and 1 inch wide are useful. All flat brushes should have chiseled edges. For flowing varnish, it is necessary to have thick, flat, camel's-hair brushes, running up to 3½ inches in width, although most house varnishing may be done with brushes not over 2½ inches wide.

Besides paint brushes, the workman will need some ordinary *scrubbing brushes* and one or two painter's *dusting brushes,* to have the surface properly cleaned.

Steel-wire brushes, with stiff steel wire instead of bristles, shaped like scrubbing brushes, are used for cleaning off old paint and for cleaning structural metal work. These are of various sizes; and the steel wires are of different lengths and sizes, hence differing in stiffness. They may be had at hardware stores.

Care of Brushes Hair and bristle brushes must be kept clean and soft; this can be done by care and faithfulness. They should not be allowed to become dry with paint or varnish in them. To prevent this, wash them out in oil or turpentine as soon as you are through using them; or they may be left in the paint or varnish for a few days. They may be kept over night by wrapping them very closely in paper if they have been used in a slow-drying material; in this way they may be carried from one place to another. Brushes should not be left to dry with even clean oil or turpentine in them; if they are to be put away, they should be well washed first with soap and water, then with clean water, then hung up until thoroughly dry.

In use, brushes are best kept in what is called a *brush safe*. A deep wooden pail, with nails driven in its sides at different distances from the bottom, and with a close cover, makes a good receptacle for brushes. The brushes have holes in their handles, or loops of cord tied to them, and are hung on these nails; their bristles dip into some turpentine or oil in the bottom of the pail; they are so hung that they do not dip into the liquid above where the bristles project from the binding. If brushes are left standing on the bristles on the bottom of a vessel, they soon become one-sided and distorted in shape. Tin brush-safes may be bought of any large dealer in brushes.

A brush which has dried with paint or varnish in it, may be recovered by soaking it in a non-alkaline varnish-remover. This will in time soften it so that it may be used again, but it is not improved by such treatment. Brushes used in shellac should be washed out with alcohol instead of turpentine or benzine. No brush is good unless it is clean.

Fillers. Fillers are of two kinds—*paste* and *liquid*. Paste fillers are something like a very thick paint, and are composed of some solid powdered substance, usually silica or powdered quartz, mixed with a quick-drying varnish thinned with turpentine or benzine. This is applied to the dry surface of the wood with a stiff, short-bristle brush, or is put on with a clean, white cotton cloth, and well rubbed into the pores of the wood. After half an hour or so, the surface of the wood is wiped off with a wad of excelsior or a clean cloth or a piece of felt. A liquid filler is a quick-drying varnish; and most of the liquid fillers on the market are cheap rosin varnishes loaded with dryers, and should never be used. Paste fillers are the best in almost all cases.

HOUSE PAINTING

Inside Work. All window and door frames, whether they are to be finished with paint or varnish, should receive a good coat of paint made with some cheap pigment, such as iron oxide, and boiled oil, applied to the back of the frame, before they are brought from the shop to the house; this prevents the absorption of moisture and hinders decay. If they are to be painted, they should receive a priming coat in the shop, if possible; if not, it should be applied as soon as practicable. The priming coat is composed of white lead and boiled oil or raw oil, with five to ten per cent of dryer; and should be almost all oil, with very little pigment. Turpentine is not a good thing in a priming coat, because the object is to fill the pores of the wood, and turpentine evaporates. As soon as this is dry to the touch, all holes are to be filled with putty. The best putty for this purpose is white lead putty, made by mixing a little raw oil with dry white lead, or by adding dry lead to paste lead until it is of the right consistency. This kind of putty hardens quickly as compared with common putty, and is the best for this purpose. A steel putty-knife should not be used on interior woodwork, as it is almost certain to scratch it; a hardwood stick, suitably shaped, should be used. All cracks, joints, and nail-holes should be carefully filled. All knots and sappy places should be varnished with shellac varnish; this prevents the pitch and moisture from attacking the paint. The shellac should be applied where it is needed, before the priming coat. The priming coat should be given time to get quite dry; at least a day—two days, if possible; and a week is better yet. Then it is ready for the second coat. This should contain a considerable amount of turpentine. If no turpentine is used, the surface is likely to be glossy, and the next coat of paint will not adhere well; but by replacing part of the oil with turpentine, we get what painters call a *flat coat*—that is, one which is not glossy; if this is made from paste lead or any paste paint, it can be produced by thinning the paste with a mixture of oil and turpentine in equal proportions; some painters prefer one-third oil and two-thirds turpentine. This is for inside work only. This coat should be allowed to dry thoroughly; if it takes ten hours for the paint to be dry enough to handle, then at least four times ten hours *additional* should elapse before the next coat is applied; this is a good general rule; and as much more time as possible should be allowed. If the finish is to be ordinary oil paint, the next coat may be paint, thinned with about half as much turpentine as before, or with no turpentine at all. In the latter case, when the coat is thoroughly dry, it must be carefully examined, and, if glossy, it should be rubbed with something to take off the gloss; curled hair or pumice and water is often used. Then the final coat, which has no turpentine in it, may be applied.

But if the finish is to be with an enamel paint, the second coat, when quite dry, should be very lightly sandpapered with fine sandpaper, and the third coat should be of like composition to the second, treated the same way; then the enamel paint is applied. For a really first-class job, when this is quite dry, it should be rubbed down with curled hair or pumice and water, and another coat of enamel put on. If the natural gloss is not desired, it may be rubbed with pumice and water. The back and all other concealed surfaces of inside wood finish should receive a priming coat of paint to protect the wood from moisture.

Painting Plastered Walls. Old plastered walls may be painted with oil or enamel paints as though they were wood, remembering that the priming coat will have almost all of its oil absorbed by the plaster. New plastered walls do not take paint well, on account of their alkaline character, which gradually disappears with exposure to the atmosphere. It is well to let a wall remain unpainted at least a year. But if it is necessary to paint a freshly plastered wall, the wall is prepared by some painters by washing it with a solution of sugar in vinegar, the sugar uniting with the lime to some extent; or—more commonly—by washing it first with a strong solution of common alum and then with a solution of soap. After this is dry, it is washed with clean water, allowed to dry, and then painted. The alum and soap form an insoluble compound which closes the pores of the plaster to some extent, and prevents the lime from acting on the paint.

Outside Work. Exterior paints are more elastic, as they need to be far more lasting, than those used on interiors, since the effect of exposure to the sun and rain destroys paint more than almost anything else does. Paint on the interior of a house will last almost indefinitely; but on the outside the best paint is not very durable. The surface, if new, should be cleaned by brushing; knots should be shellacked; after which the priming coat should be applied. This may be the same paint which is selected for the finish, only thinned with boiled oil (or raw oil and dryer), using one to one and a-third gallons of oil to each gallon of paint. The reason why ordinary paint may not be used as a primer, is that the wood absorbs the oil, leaving the pigment as a comparatively non-adhesive powder on the surface, from which the next coat will probably peel off. The next step is to putty up all nailholes and other defects. For the second coat, many experts advise the addition of half a pint of turpentine to the gallon of paint; others make no addition to it. The third coat is applied after the second is thoroughly dry; if a week or a month can elapse between these coats, so much the better.

Repainting. If the old paint has been on a long time, it is liable to be permeated by minute cracks, which admit moisture to the surface of the wood and loosen the paint. If now we paint over this, the new paint, which shrinks in drying, tends to pull off the old paint, and of course the whole peels off in patches. If the old paint is in this state, it must be removed before the new paint is applied. This can be done by *burning off*. For this work a *painter's torch* is required, which is a lamp burning alcohol, gasoline, or kerosene, and is so constructed that a blast of flame can be directed against the surface. This melts or softens the old paint, which is then immediately scraped off with a steel scraper. The paint is not literally burned, but is softened by heat so that it can be scraped off. In some cases it is sufficient to remove as much as possible with a steel brush; this is a brush like a scrubbing brush, with steel wires instead of bristles, and, when vigorously used, will take off the loose paint.

Old paint, however, is not always in this condition. If it adheres well, it may be cleaned with an ordinary scrubbing brush and water, and when it is quite dry, the new paint may be applied. Sometimes the paint seems in good condition, only it has faded and lost its luster; in such cases a coat of boiled oil, or raw oil with dryer, is all that is needed.

It is well to paint the trim—that is, the window-casings, door-casings, corner-pieces, and the like—before painting the body of the house; then the paint can be applied to the flat surfaces more neatly than is otherwise likely to be done. Paint should be applied in thin coats, well brushed on; it is not unusual to see paint come off from re-entrant angles while it is still good on flat surfaces, because it was difficult to brush the paint properly in those places. There is a great difference in durability between a thin paint flowed on with a large, flat brush, and one of proper consistency well brushed out with a brush of medium size. In all painting on wood, it is desirable to brush it on with the grain of the wood; and by painting only a few boards at once, we may avoid laps by painting the whole length. Rough surfaces hold paint better, and more of it, than smooth. A gallon of paint will cover, one coat (on a painted or well-primed surface), about 600 square feet, not flowed on, but well brushed out in a thin film. The priming coat will not cover more than 300 or 400 square feet to the gallon. In measuring the outside of a house for surface, make no deductions for doors and windows; if the trim is to be painted a different color, from one-sixth to one-third of the paint will be required of that color. Paint should be stirred frequently while using. A coat of dry paint is from $\frac{1}{500}$ to $\frac{1}{1,000}$ of an inch in thickness.

Roof Painting. Roof paints should contain a larger proportion of oil to pigment than other paints, and less dryer (or none at all). Many think that the addition of ten to twenty per cent of fish oil to a paint for roofs is advantageous; fish oil greatly retards drying and prevents the paint from becoming brittle. Tin roofs, if new, should be thoroughly scrubbed with soap and water, or with pieces of harsh cloth, such as burlap, well wet with benzine. They may then be painted.

Paint dries relatively fast on roofs; but as a roof paint is very slow-drying, plenty of time must be allowed between coats. A new roof should receive three coats. Metal gutters and spouts are to be treated the same way. Do not forget that new tin or galvanized iron is difficult to paint; have it very thoroughly scrubbed, even though it looks perfectly clean, and then rub the paint on well with the brush. Metal spouts will usually be painted the same color as the wall of the house.

Sometimes shingle roofs are painted with fireproof paint. This is not really fireproof, but considerably retards the spread of fire, after it has become thoroughly dry; when fresh, it does not even do that; nor does it have much effect after it has been on a year or so. It may be made by adding to a gallon of any good paint about a pound of powdered boracic acid. When strongly heated, this material fuses and forms a sort of glass, which keeps the air from the wood. It is after a time washed out by the rain.

Canvas roofs are prepared in the following manner: The canvas

(10-ounce duck is often used) is first nailed down, care being taken to draw it tight; it will show some wrinkles, but these are not to be allowed to accumulate to form a large wrinkle or fold. Then the canvas is thoroughly wet; it shrinks, and all the little wrinkles disappear. It is a common practice to paint it while it is still wet, this being an exception to all other practice; but some wait until it is dry. The writer has been accustomed to the latter method, and has not found that the canvas shows wrinkles on drying, while the results are all that can be desired. A well-painted canvas roof is very durable and satisfactory.

PAINTING STRUCTURAL METAL

Steel is a more perishable material than wood, and more difficult to paint. Without regular expenditure for maintenance, wooden bridges last longer than steel ones; there are wooden roof beams a thousand years old; and iron roofs are so short-lived that they are used only over furnaces and the like, where wooden ones would take fire. The painting of structural steel is therefore important; and it is also difficult, if we are to judge by results.

In the first place comes the preparation of the surface. When we paint wood, we have the surface clean and dry; and then we soak it with oil, so as to have the paint bound to it in the most intimate manner. Iron and steel, on the other hand, always come to us dirty, and covered with oxide; and as the surface is not porous, the paint does not penetrate it, but has to stick on the outside the best way it can. If we paint over the dirt and scale, and that ever comes off, the paint comes off with it; if the metal is actively rusting, and we paint over the rust, the corrosion is perhaps made slower, but it does not stop.

Air and moisture cause rust; if we can keep them away, the metal will last; but, unfortunately, all paint is very slightly porous, and if exposed to the weather it in time deteriorates. The most essential thing in painting metal is to *get the paint on the metal,* not on an intermediate coating.

There are only two ways to clean steel perfectly. One is by pickling it in dilute acid (usually 10 to 20 per cent sulphuric acid), followed by washing to remove the acid; and the other is by the use of the sand-blast. Neither of these processes is available to the ordinary painter, who must do the next best thing. This is to remove absolutely all dirt and all loose scale and oxide. First clean off the dirt, if any, with brushes, as it would be cleaned off any other surface. Then, with scrapers and steel-wire brushes, clean off all the scale which will come off. If there is any new rust (not mill scale), it must be well scraped out and cleaned off. This is indispensable. When this is done, immediately paint it, before it begins rusting again.

One of the most popular materials for a first coat is red lead in oil. This must be mixed on the spot, shortly before it is used, because it will harden into a cake in the pail or can if allowed to stand very long. From 30 to 33 pounds of dry red lead is to be mixed with each gallon of oil—not less than 28 in any case. This is immediately painted on the metal; if it is put on in too thick a coat, it will run and be uneven. Some use raw oil, others boiled oil; it does not make much difference which is used. The paint dries rapidly; and as soon as it seems hard, a second coat of the paint can be applied. Red lead is different from all other paints in this, that it will finish hardening just as well away from the air. This is because it does not dry by oxidation, as other paints do, but by the lead combining chemically with the oil, just as water combines with Portland cement. In the opinion of the writer, red lead should have one or two coats of some good paint, other than red lead, over it. But red lead is not the only first coating which may be used. Any good paint may be used—a good graphite paint, or other carbon paint, or some of the varnish-like coatings containing linseed oil and asphaltum which are made for the purpose. It is important, in using any of these, to let plenty of time for drying elapse between coats. Not less than two coats is permissible, and three are desirable.

Projecting angles, edges, and bolt and rivet heads are the places which first show rust through the paint. This is partly because the brush draws the paint thin at such places. To overcome this, it is now becoming common practice to go over the work after the first coat, and paint all edges for about an inch from the edge or angle, and all bolt and rivet heads, with an extra or striping coat; then, when the second coat goes on over the whole, there is the equivalent of two full coats everywhere.

Painting on iron, as on wood, should be done in dry weather, when it is not very cold—at any rate not below 50° F. Full, heavy coats should be used, and well brushed on. Care must be taken to get the paint into all cracks and corners.

VARNISH

A varnish is a liquid made to be applied to a surface in a thin film, which, on exposure to the air, hardens into a protective coating that is usually glossy and almost transparent. There are two principal classes—*spirit* and *oleo-resinous varnishes.*

Spirit varnishes, of which *shellac** is the most important, are made by dissolving a resin (or sometimes some other substance) in a volatile solvent, such as alcohol. They dry by evaporation, the solvent going off and leaving the resin spread out in a thin film, the liquid or vehicle having really served as a mechanical means of spreading the resin over the surface. Shellac is a resin which comes on the market in large, thin flakes. It may be dissolved in denatured (or any other) alcohol in the following manner:

Put the alcohol in an earthenware jar, and weigh out five pounds of gum shellac for each gallon of alcohol. Just before leaving at night, carefully and gently drop the shellac, little by little, into the jar of alcohol, then put on the cover and leave it until morning. Do not on any account stir it. In the morning the flakes of shellac will be soaked and swollen; but if you had stirred them in, the night before, they would have stuck together in lumps. Now, during the day, stir the mass with a wooden stick once every hour or so; do not put any metal in it, especially iron; one iron nail will spoil the color of a whole barrel of shellac. By the next morning—perhaps before—the shellac will be ready for use. It does not make a clear solution, because the gum shellac contains some wax, which does not dissolve, and so the varnish is milky or cloudy; it is, however, ready for use. As the alcohol is volatile, the jar should be kept covered; and after it is made, the varnish should be put in glass bottles or clean tin cans.

There are many grades of shellac gum, the best being known by the letters D C; but there are others nearly as good. The common shellac is brownish yellow, and is called *orange shellac;* this is the natural shellac color. White shellac is made from this by bleaching with chlorine; but it is not of so good quality as the unbleached; it has, of course, the advantage of being much paler in color. White shellac gum will, on long standing, sometimes become insoluble. Shellac varnish may be thinned with alcohol, and often this is necessary. Shellac is too often adulterated with common rosin, which greatly lessens its value. This is easily detected by a chemical test.

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*NOTE.—By some painters, the term "varnish" is never used to include shellac. There is, however, no valid, objective reason for thus limiting the use of the term.

Damar is a white resin which is soluble in spirits of turpentine—five or six pounds of resin to a gallon of turpentine. It is the most nearly colorless varnish we have, but never becomes very hard. It is used to a considerable extent as a vehicle for white lead and zinc, to make a very white enamel paint. It is not durable if exposed to the weather.

More important than spirit varnishes are the oleo-resinous varnishes, which consist of certain resins dissolved in linseed oil, the mixture being thinned with turpentine or benzine. In making these, the resin is put in a copper kettle and heated until it is thoroughly melted; then some hot oil is added to it, and the mixture cooked until the whole is thoroughly combined. The kettle is then taken from the fire, and when partly cool, the turpentine is stirred in. The resin makes the film hard and lustrous, and the oil makes it tough. Thus the larger the proportion of resin, the harder and more brilliant will be the film; the larger the proportion of oil, the tougher, more elastic, and more durable it will be, and the slower it will dry. Most of the color of varnish comes from the resin; the paler this is, the paler will be the varnish. The pale gums are higher in price than the dark ones, but are no better in any respect except color. Dark varnishes may be just as good (except in color) as pale ones—in fact may be better, for the dark resins are often harder and better than the pale ones of the same sort. The hard and quick-drying varnishes are suitable for furniture; the medium, for interior house-varnishes; the slow and elastic, for exposure to the weather.

Varnishing. The wood should be dry. For this reason it is better, if necessary to clean it, to avoid washing as much as possible, using sandpaper instead, which will also make it smooth. Of course the carpenter is supposed to do this, but the painter must not neglect it on that account. When in proper condition, it first receives, if it is an *open-grain* wood, a coat of paste filler. The open-grained woods in most common use are oak, chestnut, and ash. The woods classed as *close-grain* woods are white pine, maple, birch, yellow pine, whitewood, cherry, and sycamore. These latter do not need filling. If filler is used, it should be well rubbed in with a short, stiff brush; and when it has set, say in fifteen to thirty minutes, it is rubbed off with a handful of excelsior, rubbing across the grain, and rubbing hard, so as to force the filler well into the pores of the wood. Then it should stand 24 to 48 hours.

When purchased, a paste filler is too thick to be used with a brush, and must be thinned with turpentine or benzine; at the same time it may be stained to any desired color with an oil or varnish stain. These stains can be purchased of any desired color. If a close-grained wood is under treatment, the first thing is to apply a stain if it is desired to stain the wood; but it is common practice to finish in the natural color. Stains usually require a good deal of thinning before using; the amount of thinning will determine the depth of color. Water or acid stains are frequently used, but as they tend to raise the grain of the wood, the surfaces should be slightly sandpapered before the finish is applied.

In cleaning off the filler, be careful to clean out corners and mouldings with properly shaped hardwood sticks; do not use any steel tool.

Where rooms are to be finished in the natural color of the wood, it is nevertheless a common practice to stain the window-sashes; a cherry or light mahogany stain is often used. Fillers are sometimes used on close-grain woods; but this is not advisable, as they tend to prevent the varnish from getting a good hold on the wood.

Next comes the varnishing. Window-sills, jambs, inside blinds, and other surfaces exposed to the direct rays of the sun, are to be treated as exterior woodwork, and are not varnished with the ordinary interior varnish used on the rest of the work. The floors also are left out of account for the present. The rest of the woodwork receives its first coat of varnish; apply it, as much as possible, with the grain of the wood, brushing it out well in a thin coat. The varnish ought to dry dust free (*i.e.*, so that dust will not stick to it) over night; but at least five days should elapse between coats. When dry, it should be rubbed with curled hair or excelsior enough to remove the gloss, so that the next coat of varnish will adhere properly; a better result will be had if it is lightly sandpapered with 00 paper. The second coat is treated like the first. The third is not sandpapered, but rubbed with curled hair; the fourth or finishing coat may be left with the natural gloss, or, if preferred, it may be rubbed with fine pumice and water to a smooth, dull surface. For this purpose the varnish dealers sell felt, about an inch thick, which is well wet in clean water; a little dry pumice powder is put on it; and the rubbing is done with this. The varnish must be quite hard and dry before this is attempted. Varnishing, if properly done, is slow work; that is, much time must be allowed for each coat to dry thoroughly.

The varnish which is used on interior woodwork should not dry too quickly; it should dry enough over night so that dust will not stick to it, and in twenty-four hours should be hard enough to handle freely; but if a chair, for example, were varnished with it, it would not be entirely safe to sit on it for a week. It should, however, finally become perfectly free from tack, which it will not do if it is a rosin varnish. At present prices (and it is not probable that they will ever be lower) varnishes for interior woodwork are sold, according to color and quality, at prices ranging from $2.50 to $4.00 a gallon. It is in the highest degree inadmissible to use a cheap varnish for undercoats; the outer coats will crack if this is done. A good varnish that dries too quickly, such as what is called a *rubbing varnish,* or one intended for furniture, has not the durability needed for this work. It is economy to use a good varnish. The writer has in mind a house which was properly varnished eighteen years ago and has been constantly occupied by a large family, yet the varnish is still in fair condition; if it were lightly sandpapered and one new coat applied, it would be like new—as good as it is possible for a surface to be. Cheap rosin varnishes never look well, even when new, never keep clean, and deteriorate rapidly.

Shellac. Interiors are sometimes finished with shellac. This varnish is not used on exterior work, but it is a good varnish for interiors. All varnishes containing oil darken the color of wood; but white shellac is comparatively free from this objection; at any rate it does it less than anything else. Orange shellac is a dark varnish, and even white shellac darkens with age to an appreciable degree. Orange shellac is more durable than white, and should be used wherever admissible, rather than white; but it is usually necessary to use white shellac for this service. If shellac is made up as heavy as has been described—five pounds to a gallon of alcohol, and this is the standard —it should be thinned considerably with alcohol before using on interior woodwork. It must be applied in thin coats, and given plenty of time to dry. It is very deceptive about this; it appears to be dry and hard in an hour, and it is hard enough to handle freely; but if we apply coat after coat, even six hours apart, we shall find that the wood is finally covered with a waxy mess which will be the source of nothing but trouble. The first coat sinks rapidly into the wood; a second coat may be applied six hours later; but after that, allow two days at least between coats. Shellac makes a very thin coat; so it is necessary to apply a large number of coats, at least twice as many as of oleoresinous varnishes, to get a sufficient thickness of coating. Because of this labor, shellac is an expensive finish; but it is handsome and durable. The treatment of it, as regards rubbing, etc., is the same as has been described for other varnish.

Varnish makers usually advise that shellac should never be used as a priming coat for other varnish; this is probably because they wish to sell more of their own goods, for shellac is really an excellent first coat, except for exterior work, where it should not be used. Of course, wood should be filled before shellacking, the same as for other varnish. Varnish does not, however, wear well over a heavily shellacked surface. Shellac makes a good floor varnish, discoloring the wood very little, and wearing fairly well. After the floor has been well varnished with it, very thin coats, applied rather frequently—say every one to four months, according to use—will keep the floor in fine condition; and after applying one of these thin coats (of thinned shellac), it will be dry enough to use in an hour. This can be applied with a very wide, flat brush, and a man can go over the floor of an ordinary room in a few minutes. Shellac brushes should be washed out with alcohol immediately after using.

Exterior Varnishing. Varnishes dry much more rapidly out of doors than within, so that it is practicable to use more elastic and durable materials. The conditions, in fact, are so severe that the best are not good enough. In the first place, do not use any filler on exterior work; it will probably crumble and come out. Do not use shellac; as an undercoat exposed to the hot sun, it will soften and blister. Use only the best *spar varnish,* such as is made for varnishing the spars of yachts; fill the wood with it; sandpaper lightly between coats, just enough so that each succeeding coat will take hold well; finish with a coat well flowed on; and leave it with its natural gloss, which is more lasting than a rubbed surface. This is the treatment for hand-rails, outside doors, inside blinds, window-sills and jambs, and everything exposed to the direct sun. Hand-rails and outside doors should be refinished every year; varnish will not last on an outside door more than one-twentieth as long as it will on an inside door. Never use interior varnish for outside work.

ENAMEL PAINTS

Varnishes are all more or less brownish yellow or yellowish brown. Therefore a coat of varnish applied over a paint obscures and changes its color to some extent. To overcome this as much as possible, the varnish, instead of oil, is mixed with the pigment, as a vehicle. In this way the pigment comes to the surface and displays its color. These paints, if made with good varnish, are durable; the method of application has already been described. If necessary to thin them, do it with spar varnish instead of oil; a good interior varnish may be used, but it injures the flowing quality of the paint somewhat.

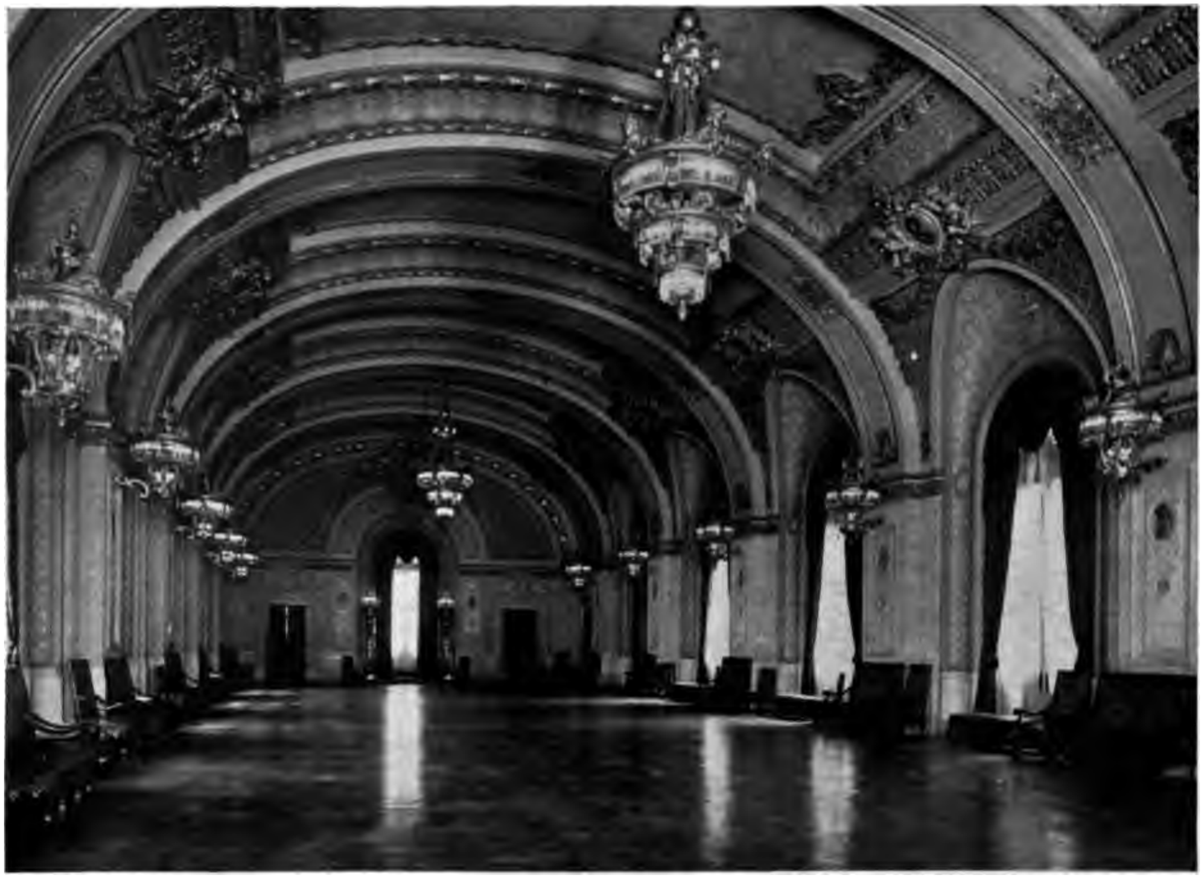
White lead and zinc are sometimes mixed with damar varnish. This makes the whitest enamel paint, but it never gets very hard, never has much luster, and is not very durable. It is very white, is easily applied, and dries quickly.

A NEW VARNISH FINISH

A method of finishing open-grained interior woodwork, which has been practiced for a few years, consists in first staining the wood with a water-stain—dyeing it, usually—and then, when it is dry, filling the pores of the wood with a paste filler which has been colored by the addition of a pigment. For example, the wood may receive a stain of any dark color, and the wood-filler be mixed with white lead. This shows the open or porous part of the grain in white on a dark background. By using artistic combinations of color in the stain and filler, very beautiful effects can be produced, and this finish has been used in some of the most handsome and costly public and private buildings. Thus, if a room is to be decorated in green, the woodwork can be made to harmonize with the prevailing color. An oil stain must not be used on the wood, as it will not work well with the filler. The colored filler is applied and rubbed off in the same way that any paste filler is used, and then the varnish is applied over it in the usual way.

FLOOR FINISHING

The primary trouble with floors is that people walk on them. If they did not, there would be no trouble at all. Four coats of varnish,



BALLROOM OF LA SALLE HOTEL, CHICAGO
Holabird and Roche, Architects, Chicago

or even paint, having an aggregate thickness of less than one one-hundredth of an inch, will not last indefinitely under the wear of nail-shod heels.

Probably the simplest treatment for floors is painting them. The paint should contain a large proportion of a hard oleo-resinous varnish; an ordinary oil paint is not hard enough. If an oil paint is used, it must be heavily charged with dryer, for a floor paint should dry in twelve hours. Good quick-drying floor paints are in the market.

Floors of choice wood, however, are not usually painted; they may be either varnished or waxed. If they are of oak or other open-grained wood, they must be filled with a paste filler; otherwise the varnish is applied directly to the wood. Floor varnish is quicker in drying, and harder than interior finishing varnish, but should not be so hard as to be brittle; rubbing varnish is too hard. If the floor is to be stained, this is done with an oil stain before varnishing; if it is a floor which has previously been varnished, so that the stain will not penetrate the wood, the stain may be mixed with the varnish, although the effect is not then so good.

Floor wax is not made of beeswax, but of a harder vegetable wax, and is sold by all paint dealers. The floor should receive one coat of shellac; then the floor wax may be rubbed on with a stiff brush, and when it is dry, which will be in a few hours, it may be polished by rubbing with a clean cloth or with a heavy, weighted floor brush made for the purpose. It should receive another coat every week until four or six coats have been applied; after this a little of the floor wax, thinned if necessary with turpentine, should be applied often enough to keep the floor looking well. Alkalies dissolve the wax, and in cleaning the floor only a little soap should be used in the water with which the floor is washed. A wax finish kept polished with a polishing brush, is the handsomest surface than can be obtained for a floor; but it is so slippery that it is somewhat dangerous. It does not discolor the wood. Interior trim (but not hand-rails) is sometimes wax-finished. This finish requires a good deal of care, as it is likely to catch dust; otherwise it is handsome and durable.

Old floors which require cleaning and revarnishing should have the old varnish or paint removed by a good *varnish-remover*, one of the modern sort, free from alkali. This is painted over the surface, and, after a short time, removed with a scraper. The last of the varnish-remover is taken out with a rag wet with turpentine or benzine, care being taken that there is no fire of any sort in the room or any neighboring room. This will not only take off the old varnish, but the old filler also; and the floor must be treated like a new floor. Any stains on the floor may be treated with a hot solution of oxalic acid, one part to ten of water; when the stains disappear, wash well with clear water; let the floor dry a day; sandpaper; and it is ready for varnishing again. This treatment—removal of old paint or varnish by a liquid varnish-remover—is applicable to all varnished or painted work. The outside of a house could have the old paint taken off in this way, but *burning off* is cheaper and quicker. These varnish-removers are mixtures of benzole, acetone, alcohol, and other liquids, and the best of them are patented.

ALUMINUM AND BRONZE PAINTS

Radiators and pipes are often painted with aluminum or bronze paints. These consist of metallic powders, in fine flakes, mixed with some varnish—usually with a pyroxylin varnish, which is a thin solution of a variety of gun-cotton in a suitable solvent, generally acetate of amyl. If one of these paints—which smell somewhat like bananas—becomes thickened in the can by evaporation, it can usually be thinned with acetate of amyl, if some of the special thinner cannot be had; brushes can be washed out in the same. A good aluminum paint is durable, even exposed to the weather. One coat is usually enough, two certainly so.

GLAZING

House painters are usually expected to understand the art of setting window-glass; it is not difficult to learn. Glass is classified as *sheet* or *cylinder glass* and *plate glass*. Sheet glass is made, at the glass works, by blowing a quantity of glass, first, into a hollow globe; then, by more blowing and manipulation, this is stretched out into a hollow cylinder perhaps a foot in diameter and five feet long; this cylinder (whence the name "cylinder glass") is cut open, and, after reheating, is flattened out into a sheet, whence the name "sheet glass;" after annealing, it is cut up into convenient sizes. It is made of two thicknesses—*single thick*, which is about one-sixteenth of an inch; and *double thick*, one-eighth of an inch; but it does not run perfectly uniform. All sheet glass contains streaks, bubbles, and specks of dirt, and is more or less irregular or wavy in its surface; and in respect to this it is graded as first, second, and third quality; in American glass these grades are usually marked "AA," "A," and "B;" and anything poorer than "B" is called *stock sheets*. Foreign glass is not thus marked, each maker having his own arbitrary marks. Single-thick glass is used for sizes not greater than about 28 by 34 inches; double-thick, up to 40 by 60. For larger sizes, plate glass only is used; but of course either plate or double-thick can be used for small sizes, if desired.

Plate glass is cast in plates; the liquid glass is poured out on an iron table, about 15 feet wide and 25 feet long, and smoothed down to a uniform thickness of half or five-eighths of an inch by passing a roller over it, like rolling pie-crust; after this it is ground down with sand, emery, and polishing powder to a quarter or five-sixteenths of an inch in thickness. It is therefore much more costly than sheet glass, but is also more perfect.

Crystal is a very thin plate glass, about one-eighth of an inch thick, and is used where ordinary plate is too heavy, as in movable sash. It is the finest of all window glass. There are two grades of plate glass, known as *glazing* (for windows) and *silvering* (for mirrors), the latter being the best. In the first place, the sash is prepared for the glass. It must receive a priming coat; if it is to be painted, it is primed with white lead and boiled linseed oil, the mixture having very little or no turpentine added; if it is to be varnished, it is primed with boiled oil alone. If it is not primed, the putty will not stick; the wood will draw the oil out of the putty and leave it crumbly. Next, the glass is fitted to the sash. It is cut either with a glass-cutter's diamond or with a wheel cutter, the latter being a little sharp-edged steel wheel set in a handle. If well made, the wheels may be bought separate and are replaceable. The wheel cutters are generally used on sheet glass; but plate glass is cut only with a diamond, which makes a deeper cut. The wheels are kept wet with kerosene; the workman has a little bottle or cup of kerosene on the bench, and dips the wheel in it.

The glass being cut to the right size, a layer of putty is spread, with the putty-knife, along the recess in the sash where the glass is to rest. This is called *bedding* the glass, and should always be done. It is not uncommonly omitted with pine sash; but it absolutely must be done with all hardwood sash, metal or metal-lined sash, and for all plate and crystal glass; and it ought to be done in all cases. Then the glass is gently pressed into place, after which it is fastened with *glaziers' points,* which are triangular bits of metal. No. 2 points are used on single-thick, and No. 1, which are larger, are used on double-thick glass; they are put in 9 to 12 inches apart. They are driven, not with a hammer, but with the thin side of a two-inch chisel, the flat side of which lies on the glass, the edge of the chisel away from the surface so as to avoid scratching it. The chisel is also useful for adjusting the position of the pane; if it is smaller than the sash, it is so placed that when the sash is in its natural upright position the pane of glass will rest with its lower edge bearing on the wood. The points are commonly of zinc, which bends easily; and when the pane is properly placed, if there is on one side a space between it and the wood, the chisel is held over this crack, and with its edge an indentation or crimp is made in the little triangular zinc point which has already been driven; this crimp prevents the glass from sliding back against the wood. This is the reason zinc is used for the points; it will bend. Steel points are sometimes used for plate glass, because of their greater strength, the glass being heavy. To drive through the sheet metal of metal-covered sash, steel slugs are used; these are about $\frac{1}{20}$ inch thick, about $\frac{7}{8}$ inch long, and $\frac{7}{16}$ inch wide at the wide end, triangular, and sharp-pointed.

There is a machine for driving points, but it is not much used except on small glass set in soft-wood sash.

The glass being properly secured by points, it is ready for puttying. To do this, the professionals set the sash up in a nearly vertical position on an easel; the glass is puttied on the right-hand side and across the bottom; then the sash is turned the other edge up, and the operation is repeated. This finishes the work.

The most important things about glazing are to use a sufficient number of points and to use good putty. Ordinary (pure) putty is made of whiting, which is pulverized chalk, mixed with enough linseed oil to give it the consistence of stiff dough. The workman can make it from these materials with his hands; everyone can make his own putty. As a matter of fact, however, the putty of commerce is made by machinery; and also, as a matter of fact, it is in general abominably adulterated. It would seem as though whiting and linseed oil were materials cheap enough; and in reality putty can be sold for about three cents a pound, or sixty dollars a ton; and a dollar's worth will putty all the glass in an ordinary house. Pure putty, however, is almost impossible to get. Marble dust is substituted for whiting, and a mixture of rosin and mineral oils for the oil, and the cost reduced about half. It is the use of this miserable stuff which causes nine-tenths of the troubles with windows. If the glazier cannot be sure of his putty otherwise, he should make it himself.

The best putty for glazing is a mixture of pure whiting putty with one-tenth white lead putty. This makes it set a little more quickly, and it becomes harder. Pure white lead putty gets too hard; it is too difficult to remove it in case of breakage of glass.

If the glass has not been bedded in putty, it is customary to go around the indoors side of the glass, and crowd some putty into the crack between it and the sash. This is called *backing* the glass. Large plates of plate glass are not puttied, but are held in place with strips of moulding nailed on the sash, in which case the crack between the glass and the moulding is backed with putty.

REVIEW QUESTIONS

REVIEW QUESTIONS

ON THE SUBJECT OF

UNDERWRITERS' REQUIREMENTS

PART I

---

1. Explain briefly the electrical causes of fires.

2. State in general terms the means to be taken in every installation to guard against such fires being started.

3. As affecting the fire hazard, describe the essential differences between

   (a) constant-current systems and constant-potential systems;

   (b) low-voltage and high-voltage circuits.

4. What is the National Electrical Code?

5. Into what main subdivisions are its rules divided?

6. Describe the chief desirable characteristics of a generating station with regard to the fire hazard.

7. In judging the safety of an installation of electric motors, what are the chief items to be considered?

8. Describe a motor-starting rheostat.

9. What is an autostarter?

10. What is the object of a continuous duty resistance?

11. What are transformers?

12. State the advantages of the use of transformers with regard to the fire hazard.

13. What precautions must be observed in installing transformers?

14. Outline the standard practice for outside wiring.

15. What is electrolysis?

REVIEW QUESTIONS

ON THE SUBJECT OF

UNDERWRITERS' REQUIREMENTS

PART II

---

1. What is open-work wiring?

2. What is the essential principle of conduit work?

3. What are the advantages and disadvantages of concealed work?

4. Outline the chief things to be considered in electric installations when subject to a continual dampness.

5. When should wood molding never be used?

6. What are the chief points to be observed in wiring a theater?

7. How should the footlights be installed?

8. With a voltmeter having a resistance of 24,000 ohms and a battery of 26 volts, it was found that the voltmeter read 6 volts when connected in series with the battery and the wiring of a house. What was the insulation resistance of the wiring?

9. Why are rubber-covered wires used almost exclusively in all inside wiring?

10. What is a "slow-burning" wire?

11. Describe a "weatherproof" wire.

12. Give the dimensions of a cartridge fuse for a circuit of 110 volts, 20 amperes.

13. In what way do telephone wires in a home affect the fire hazard and what fire precautions should be taken?

14. What is a snap switch and what is its distinguishing feature?

15. Describe a characteristic conduit installation for an apartment.

REVIEW QUESTIONS

ON THE SUBJECT OF

ELECTRIC LIGHTING

1. State the current, voltage, candle-power, and efficiency of the incandescent lamp most commonly used.
2. What do you understand by the "smashing point"?
3. Give the main points of difference between the three forms of arc lamp mechanism.
4. Mention the three principal parts of the Nernst lamp.
5. Describe with sketch the anti-parallel system of feeding.
6. Prove the law that illumination varies inversely with the square of the distance.
7. Why is arc light photometry a more difficult problem than incandescent?
8. Calculate the illumination three feet above the floor at the center of a room 18 feet square and 12 feet high, lighted by four 10-candle-power lamps 9 feet above the floor at the center of the side walls, assuming the coefficient of reflection to be 50%.
9. What material is used for the filament of incandescent lamps? Explain why.
10. From the curve given in Fig. 4, determine the efficiency which corresponds to the temperature of 1300° centigrade.
11. What is the object of double carbons in an arc lamp?
12. What is meant by mean spherical candle-power?
13. What is the function of the heater in the Nernst lamp?
14. Describe the Bunsen photometer.
15. How does the lighting of public halls differ from that of residences?
16. Why cannot platinum wire be used for the filament of incandescent lamps?

REVIEW QUESTIONS

ON THE SUBJECT OF

SHEET METAL WORK

1. What care must be taken when notching tin plate for flat seam roofing? State the reasons why.
2. What care must be taken when the sheets are painted on the underside?
3. In putting in flashing why is a base and counter flashing preferable to a full flashing?
4. What is the object in using cleats in roofing?
5. When are valley sheets employed?
6. How is a water-tight joint obtained between stone and metal?
7. What style soldering coppers are used for roofing, and why is the small groove filed on its lower side?
8. What style soldering coppers are used for upright soldering, and how are they tinned ready for soldering?
9. What is liable to occur when a roof is painted and the rosin has not been scraped off?
10. What is liable to happen when galvanized iron and copper are joined together?
11. How can the disturbance between the two metals be prevented?
12. Describe the laying of a valley in a corrugated iron roof.
13. What is used to make tight joints in roofing, where no solder is employed?
14. When a corrugated iron roof is laid on sheathing, how is it fastened?
15. When the same roof is laid on iron framing, how is it fastened?
16. How are the hip ridges fastened and made tight over corrugated iron roofing?
17. What is known by a side wall flashing in a corrugated iron roof?
18. How is this side wall flashing made water-tight?
19. What is known as an end wall flashing, and how is this flashed?

REVIEW QUESTIONS

ON THE SUBJECT OF

PLASTERING

---

1. Describe the proper method of spacing, nailing, and joining wood lath.

2. Of what materials is mortar composed? What are the requirements of each to insure good results?

3. Compare the relative advantages of metal and wood lathing for both interior and exterior plastering.

4. How are estimates for lathing and plastering made?

5. What precautions are absolutely necessary in the placing of metal lath?

6. If wood lathing is used on exterior work, how should it be laid?

7. When, if ever, is wire lath preferable to expanded metal?

8. Describe in detail the process of slaking the lime and mixing the mortar for ordinary interior plaster work in dwelling-houses. What precautions are to be observed?

9. Should mortar be used as soon as mixed? Discuss this question in all its bearings.

10. How would you mix the mortar for exterior work?

11. If lime is not thoroughly slaked, what trouble is likely to develop?

12. What will be the effect of using too much lime in mixing mortar? Too much sand?

13. What are the essentials for durable exterior plastering?

14. Discuss the relative advantages of three-coat and two-coat work. In what kind of work are three coats always necessary?

15. In interior work, what precautions must be observed in laying the successive coats of plaster? In exterior work?

REVIEW QUESTIONS

ON THE SUBJECT OF

PAINTING

1. What is the difference between raw and boiled oil? When is one preferable to the other?

2. What would you consider a good brush outfit for painting and varnishing the interior woodwork and exterior finish of a modern frame dwelling?

3. How would you make your own putty if you could not buy a satisfactory grade?

4. Describe the principal ingredients used as *pigments*. As *vehicles*.

5. What are *thinners? Dryers? Fillers?*

6. How are painters' brushes kept in good condition?

7. How are paints adulterated?

8. Describe the process of mixing the successive coats of paint for ordinary interior (not floor) and exterior woodwork.

9. Describe the process of preparing the woodwork and applying the successive coats of paint in ordinary interior (not floor) and exterior work.

10. What points require particular attention in the repainting of an old job?

11. Describe the process of painting a plastered wall.

12. Describe the material and methods of work in roof painting.

13. What is enamel paint? How would you do a job of enameling the woodwork, say, in a bathroom?

14. Describe in detail the process of painting structural metal.

15. How are varnishes classified?

16. Describe the method of preparing and applying shellac varnish.

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